TRANSIT
AND THE
ENVIRONMENT

Prepared for BC Transit

by TransVision Consultants Ltd.

April 1990

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SUMMARY

This report outlines the importance of transit to the life of a community in terms of contributing to the environmental well-being of the area. A large part of this importance to the environment is due to the diversion of potential automobile users to higher capacity modes of transit. Transit in the Greater Vancouver Regional District contributes to the environment by reducing air pollution, noise, congestion, accidents and the land consumed by roads and parking facilities. When it comes to transporting large volumes of people in urban areas, transit is environmentally less disruptive than the automobile. Transit also contributes to the growth and vitability of the urban core and other present and planned major activity centres.

On a passenger-kilometer basis, the conventional diesel bus is eight times more energy efficient than the automobile. As a result, the diesel bus produces one-quarter the amount of nitrogen oxides, one-twentieth the amount of carbon monoxide and one-fiftieth the amount of hydrocarbons that automobiles tend to produce. Carbon dioxide, a large part of automobile exhaust emissions, is also of concern, contributing as it does to the greenhouse effect. Since trolley buses and SkyTrain vehicles produce negligible air pollution due to the prevalence of hydro-electricity in British Columbia, these will be important components of any environmental strategy for transit in the future.

A hypothetical situation focuses on what Vancouver might be like today if transit had not had such a high local and provincial priority. This brief theoretical view of the Greater Vancouver Regional District without transit is useful in illustrating the types of social costs which might

result in the absence of transit. Not only would personal expenditures on transportation be higher, but significant public and private sector resources would have to be devoted exclusively to accommodating the automobile. As well, society as a whole would be burdened with higher pollution levels and a reduced quality of life. In summary, urban transit in the Greater Vancouver Regional District currently saves the residents and the environment of the lower mainland every year:

116 million litres of gasoline
26 million kilograms of air pollutants
8 million kilograms of road dust
$278 million in automobile and highway costs

If additional funds could be invested in public transit with the objective of encouraging another five percent of the peak period trips to use transit instead of private automobiles, the transit system could save the residents and the environment of the lower mainland every year:

22.6 million litres of gasoline
5.3 million kilograms of air pollutants
1.5 million kilograms of road dust
50.7 million kilograms of carbon dioxide

1. The Urban Environment

The environment used to mean simply that which surrounds, but the term has now acquired a much wider connotation. While pollution and other nuisances are phenomena which can be defined and measured more or less exactly, the concept of the environment involves not only, physical, chemical and biological factors but also psychological aspects which are appraised differently by every individual.

Environmental problems, on which more and more attention is being focused, are the consequence of industrial development, the extension of urbanization, the growth of population and the considerable increase in consumption which accompanies rising living standards. Pollution is increasing and ecological theories state that pollution of all kinds resulting from human activities may upset the equilibrium of the cycles of the biosphere, an equilibrium which is essential to life. Faced with menacing environmental hazards, the public and government have in many cases joined battle against threats to the environment.

In urban centres, transit contributes to limiting congestion, thus enhancing the environment. It is also subject to environmental constraints when it is unable to proceed smoothly and regularly. These matters need review in the context of attempting to provide a transit service that is 'environmentally-friendly'. It is in this context that the proposed report endeavours, without claiming to give an exhaustive treatment of this wide field, to situate transit in the environment, to evaluate its contribution to reducing air and noise pollution, to indicate the constraints to which it is subject, and to review the contribution which the various forms of transit make to the struggle to preserve and improve the environment.

TRANSPORTATION AND THE ENVIRONMENT

Transportation has both positive and negative effects on the environment. Only certain impacts, such as changes in air quality, visual appearance, noise levels, and overall effect on the urban environment, can be effectively quantified and evaluated. Others, such as aesthetics, effects on neighbourhoods, and social impacts, are more difficult to measure.

Air pollution from engine emissions. According to studies undertaken by the Pollution Control Division of the Greater Vancouver Regional District, 84.1 percent of all air pollution resulted from transportation, by far the largest single source (second on the list was industrial processes with 9.2 percent). Emissions from motor vehicles alone account for 75.9 percent of all air pollution.

Noise pollution from urban traffic. Although noise can be extremely annoying, and even physically and mentally harmful to some people, housing continues to be built next to heavily travelled roads. Many people appear willing to trade off noise levels for improved accessibility. Many others, however, have little choice.

Water pollution from storm runoff. Hard-surface roads, graded streets and parking lots increase the amount and rate of runoff to receiving watercourses, create erosion and contribute to water pollution. Highway surfaces accumulate rubber particles, asbestos from brake linings, oil and grease, gasoline, deicing salt or calcium chloride, heavy metals from air pollution, and compounds from the pavement. Eventually, these are likely to end up in watercourses.

Damage to roadside vegetation. Use of deicing salt can damage roadside vegetation and produce other environmental impacts including contamination of surface and ground water. Spraying road rights-of-way with herbicides for weed control can be similarly harmful. Construction can expose roots, lower water tables and possibly destroy roadside trees.

Altered quality of life. A new transportation facility providing improved access for residents of a region can substantially change -- not always for the better -- the lifestyle of the people and communities affected.

Environmental considerations discussed in this report are limited to those elements and factors that have readily definable qualitative and quantitative limits. Clear and concise definitions are a prerequisite to understanding environmental considerations. Pollution and adverse impact are separated in the discussion because they represent different characteristics of the problem. Quantitative factors such as traffic congestion, energy consumption, air pollution and noise pollution are considered. Other environmental aspects, such as aesthetics, effects on neighbourhoods, and social impacts, are not discussed in this report.

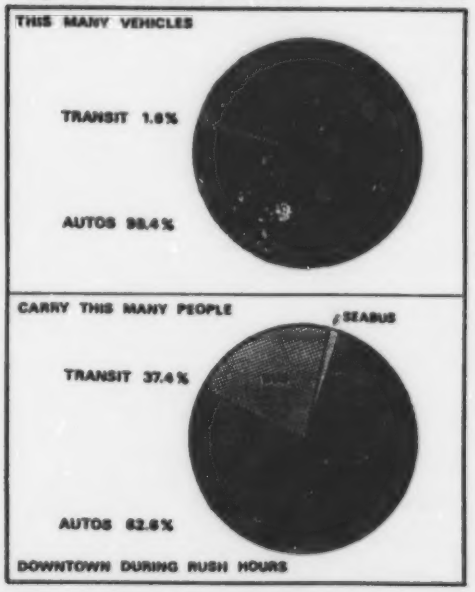
TRANSIT'S ROLE IN TRANSPORTATION

The role of transit in the urban transportation system is to move people. Urban transit is very simply: "People Moving People".

Transit services and facilities are designed to provide mobility and accessibility for the masses of people without access to an automobile, and as a viable alternative for auto users who would rather leave their car at home. Transit has a role to play in meeting the community's transportation needs and in reducing automobile congestion which characterizes the world's major urban centres.

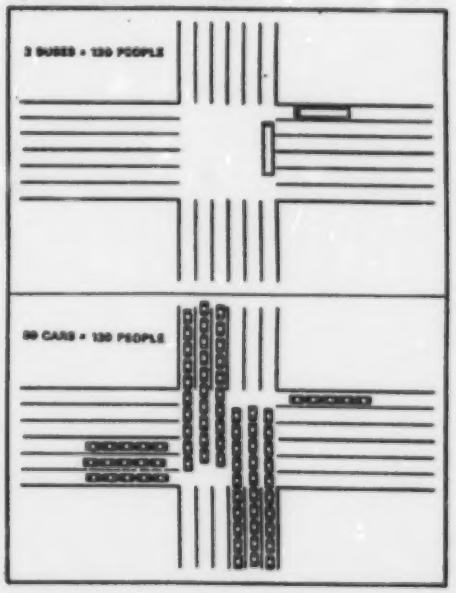
Transit services and facilities benefit all motor vehicle operators and their passengers by diverting some potential automobile users to higher capacity modes of transit. This in turn reduces the number of vehicles on the road and increases the mobility of those who choose to travel by automobile. For very 50 persons diverted to public transit, there are approximately 38 fewer automobiles using the road network. The exhibit following illustrates the role of transit in urban transportation.

Comparison of Auto and Transit Usage to Downtown Vancouver *Exhibit* 1



Source: *1985 Metropolitan Vancouver O-D Survey: Vehicle and Passenger Screenline Survey*, Greater Vancouver Regional District, Burnaby, B.C., 1985 (Adapted).

Comparison of Space Occupied by Automobiles and Buses *Exhibit* 2



Source: *Individual and Community Benefits of Public Transit Services and Facilities*, Toronto Transit Commission, Toronto, Ontario, August 1987, p.42.

2. Transit and Energy Consumption

Transportation is based on the use of power; power is the rate at which useful work is done. Power depends on energy which is the ability to do work. The success of an industrial society, the growth of its economy, the quality of the life of its people and its impact on other societies and on the total environment are determined in large part by the quantities and the kinds of energy resources it exploits and by the efficiency of its systems for converting potential energy into work and heat.

The artful manipulation of energy has been an essential component of man's ability to survive and to develop socially. Although primitive people and most animals can alter their behaviour to adapt to changing environmental conditions, the reverse ability is uniquely man's. Man has a tendency to change environmental conditions to suit their behaviour.

The use of energy has been a key to the supply of food, to physical comfort and to improving the quality of life beyond the rudimentary activities necessary for survival. The utilization of energy depends on two factors: available resources and the technological skill to convert the resources to useful heat and work. Energy resources have always been available, but power devices to convert energy into useful work is a relatively recent development.

Man has introduced himself into the natural energy cycle, converting energy from less desired forms to more desired ones, with an increasing dependence on electricity, a trend that has direct effects on gross energy consumption and indirect effects on environmental quality. In this chapter, we will look at the use of energy in transportation.

THE FLOW OF ENERGY

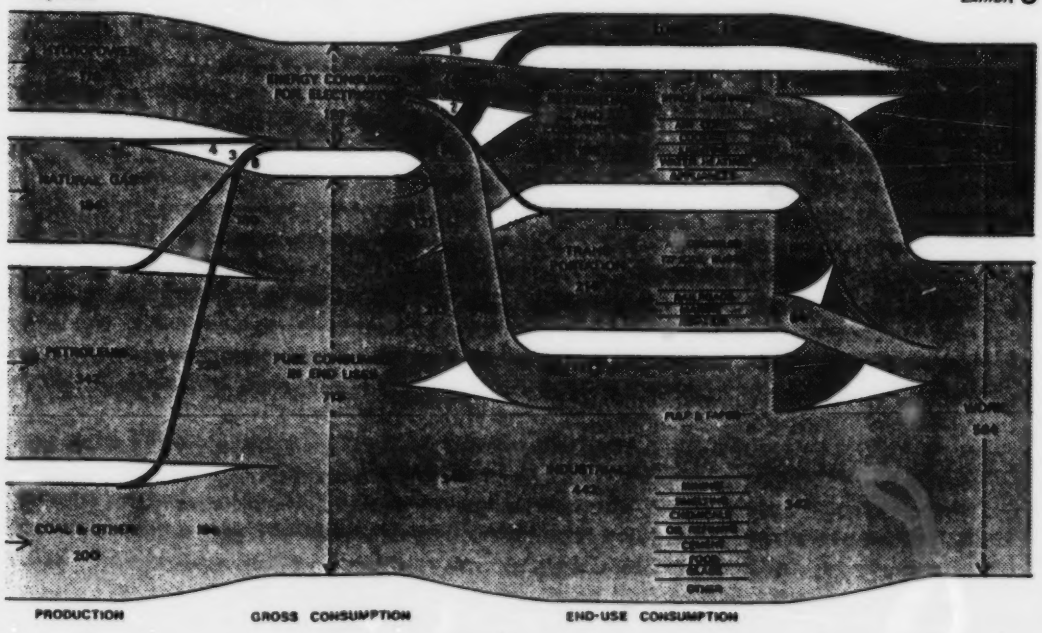
British Columbia is both a major energy producer and a major energy consumer. The Province is endowed with abundant hydroelectric resources, significant natural gas reserves, vast quantities of coal and a small amount of oil reserves. British Columbia's energy use per dollar of Gross Domestic Product (GDP) is among the highest of any region in the world, due to the Province's energy intensive industrial base -- pulp and paper, primary metals, mining and petrochemicals.

The flow of energy from resources to end users in British Columbia is charted in the exhibit below. The flow diagram shows the pathways of the energy that drives machines, provides heat for manufacturing processes, provides fuel for vehicles, and heats, cools and lights the people of the Province. It does not represent the total energy budget because it includes neither food or solar radiation.

All energy conversions are more or less inefficient, of course, as the flow diagram makes clear. In the case of electricity there are losses at the power plan, in transmission and at the point of application of power; in the case of fuels consumed in end uses the loss comes at the point of use. The 1987 gross consumption of 904 petajoules of energy in British Columbia ends up as 564 petajoules of useful work and 340 petajoules of waste heat, amounting to an overall efficiency of 62 percent.

Flow of Energy in British Columbia in 1987
Petajoules

Exhibit 3



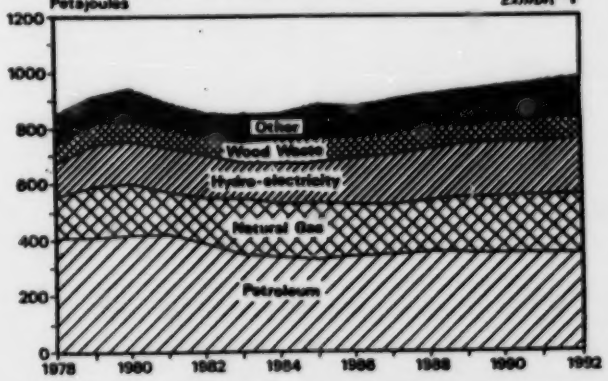
THE SOURCES OF ENERGY

British Columbians used 904 petajoules of energy in 1987, and while demand is growing, total requirements are still below a peak period reached in 1980. The exhibit shows historical and forecast energy sources by type of fuel. The largest share is held by oil products, but this is expected to decline over the forecast period. Natural gas, electricity, and other fuels (coal, wood waste, pulping liquors) are expected to capture increasing shares of the total requirements for energy supply.

Energy from petroleum products totaled 342 petajoules and represented the largest share of primary energy at 38 percent. Motor gasoline met 56 percent of the total energy requirements from petroleum but are forecast to continue the decline that began in 1980, as improvements in the average fuel efficiency of the automobile stock continue to offset increases in the number of vehicles and miles driven. Diesel fuel oil demand is expected to show some growth, however, from the present 25 percent due to increased commercial and industrial activity. Aviation fuels and heavy fuel oil complete the picture for energy from petroleum.

Natural gas supply totaled 184 petajoules, representing 20 percent of total primary energy supply. Since much of the demand for natural gas is for residential heating, the demand is largely affected by the average temperature. During both 1986 and 1987, warm weather caused natural gas requirements for space heating to be lower than normal.

Energy Supply in British Columbia
Petajoules
Exhibit 4



Source: *British Columbia Energy Supply and Requirements Forecast Update 1987-1992*, Ministry of Energy, Mines and Resources, 1987.

Provincial hydroelectric sources provided 178 petajoules, representing about 20. percent of total. energy requirments -- a large share of the energy fortunately met by this non-polluting source. Another 13 petajoules of natural gas, diesel fuel oil and other fuels were consumed in the thermal generation of electricity.

Among the other sources of energy in British Columbia are coal, wood waste, pulping liquours, waste gases and oxygenated fuels. Demand for these fuels totaled 200 petajoules in 1987 and represented 22 percent of primary energy demand. Coal consumption represented less than 1 percent of the energy supply. Wood waste and pulping liquors are used in the pulp and paper industry to produce steam for heat and electricity.

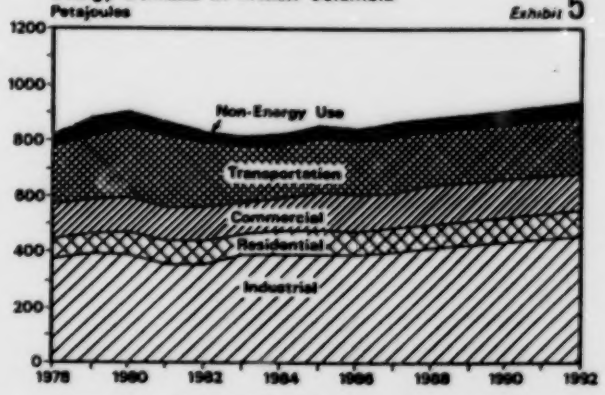
THE DEMANDS FOR ENERGY

Energy is required at the point of use, whether for heating homes and lighting offices or powering industrial boilers and providing fuel for internal combustion engines. Demands for energy are lower than the supply due to losses in the conversion of crude oil to refined products and fossil fuels into electricity. Energy is lost in the conversion process. The total energy demand in British Columbia in 1987 was 854 petajoules. Energy conservation has clearly had an impact in the province -- energy use per dollar of GDP has declined by 15 percent since 1978.

Households consume energy for lighting, space and water heating, and in appliances. In British Columbia, residential energy needs are met primarily from natural gas and electricity, with some light fuel oil consumed in areas lacking access to gas. Residential demand is presently about 118 petajoules but growth is expected to lag behind growth in housing due to continuing improvements in household energy efficiency.

Commercial sector energy demand is 80 petajoules and includes the requirements of government, finance, insurance and real estate, communications, personal and business services, and wholesale and retail trade. Energy requirements are primarily associated with lighting and space heating.

Energy Demand in British Columbia
Petajoules
Exhibit 5



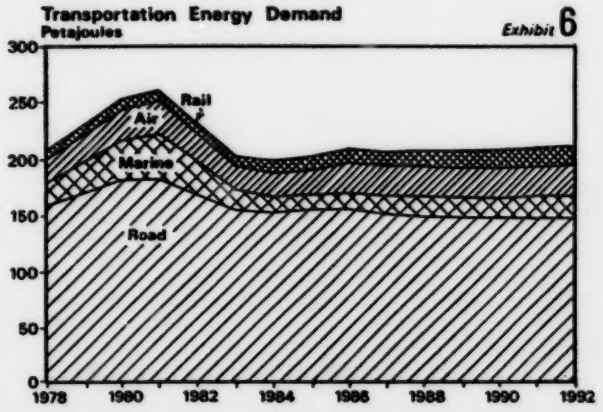
Source: *British Columbia Energy Supply and Requirements Forecast Update 1987-1992*, Ministry of Energy, Mines and Resources, 1987.

Total industrial sector energy demand is estimated at 442 petajoules in 1987. This demand is determined primarily by industrial output, and in particular by activity in the forestry and mining sectors. Pulp and paper energy demand accounted for 59 percent of total industrial requirements. Other energy-intensive industries are petrochemicals, smelting and mining. Industrial energy consumption accounted for about 52 percent of the total energy demand in British Columbia.

Energy used in road, rail, marine and air transport totaled 213 petajoules in 1987 and accounted for 25 percent of total provincial requirements. Virtually all (99 percent) of the transportation energy requirements are met by refined petroleum products, primarily motor gasoline, aviation fuel, diesel and heavy fuel oil. Small amounts of propane, natural gas and electricity are also consumed.

TRANSPORTATION ENERGY CONSUMPTION

The transportation sector includes road, rail, air and marine transport. The road sector is, by far, the largest, accounting for 76 percent of BC's total transportation energy use in 1987. Air sector energy use accounts for 22 percent of total transportation sector demand, with the rail sector accounting for 12 percent and the marine sector for 16 percent.



Source: *British Columbia Energy Supply and Requirements Forecast Update 1987-1992*, Ministry of Energy, Mines and Resources, 1987.

Petroleum products account for 99 percent of energy demand in the transportation sector. In fact, the sector's demand for oil currently is 62 percent of total oil end use. Motor gasoline dominates fuel use in transportation (56 percent), followed by diesel (25 percent) and aviation fuels (11 percent), with the remainder (8 percent) being accounted for by heavy fuel oil, propane, aviation gasoline, natural gas for vehicles and electricity.

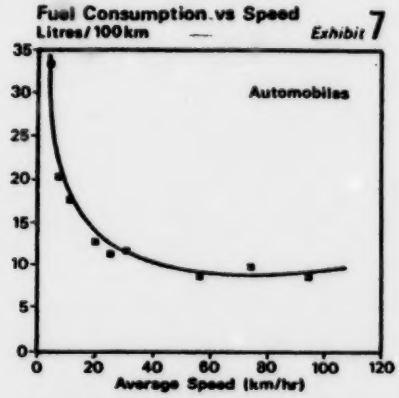
With the road sector accounting for such a large share of total transportation energy use, variations in transportation energy demand mainly reflect developments in road transport. Motor gasoline accounts for almost the entire fuel use by automobiles, while energy used to move trucks is more evenly divided between gasoline (57 percent) and diesel (40 percent). Light trucks account for about 75 percent of gasoline use by trucks while extra-heavy diesels account for 91 percent of diesel road use. Urban transit buses almost exclusively use a light diesel fuel. Trolley buses and light rail vehicles are powered by electricity.

Growth in road transportation energy demand is approximately equal to the sum of the growth rates of the stock of vehicles, the average fuel efficiency of the stock and the average distance per vehicle. Impressive gains have been made in recent years in passenger vehicle fuel efficiency as a result of downsizing, the use of lighter materials, and other technical innovations, such as electronic engine controls. The fuel efficiency of the average vehicle is expected to continue to improve.

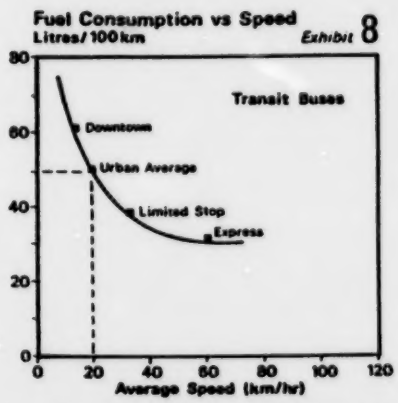
Diesel fuel oil consumption by trucks, buses and passenger vehicles is expected to remain relatively constant, as is rail transport requirements for diesel fuel and the marine sectors requirements for both diesel and heavy fuel oil, although fluctuations in the marine sector are expected.

ENERGY CONSUMPTION BY MODE

Impressive gains have been made in recent years in passenger vehicle fuel efficiency as a result of downsizing, the use of lighter materials, and other technical innovations, such as electronic engine controls. In the urban environment, attempts are continuing to improve the traffic flow. There is room for improvement. Traffic congestion -- especially during peak rush hour periods -- is a prodigious energy consumer, since slow-moving or idling vehicles consume more fuel per unit of distance than steadily moving vehicles as illustrated in the following exhibits.



Source: R. Joumard, *Real Exhaust Gaseous Emissions and Energy Consumption from the Passenger Car Fleet*, SAE Paper 881764.

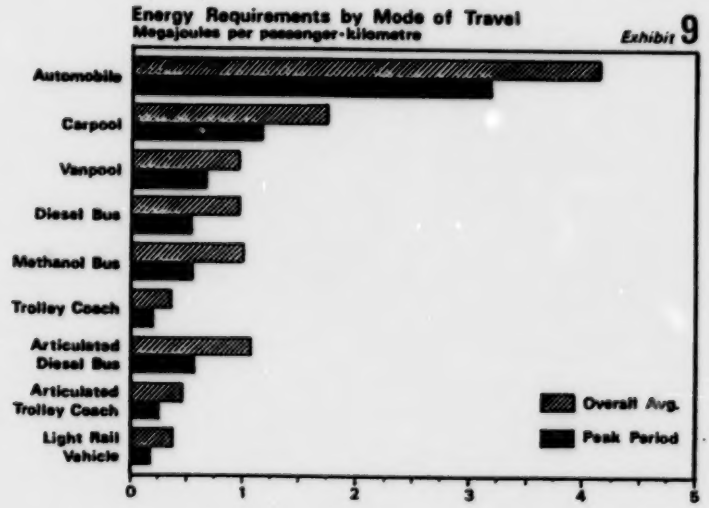


Source: Adapted from M.R. Campbell and A.M. Khan, *Urban Transportation Energy: Policy Planning and Technology Factors*, RTAC Transportation Forum, March 1985, p. 22.

Improving the flow of urban traffic could significantly reduce energy consumption. This requires emphasis on demand-management, not supply-side measures such as widening of arteries that serve as an incentive to increased road use. The following measures are demand-management measures: 'real-time' traffic light management, and measures to increase the occupancy of commuter vehicles, such as car pooling programs and expansion of high occupancy vehicle lanes. Improving the flow of traffic -- for buses and cars -- would provide for greater energy efficiency. Public transit, in particular, can benefit greatly from high occupancy vehicle lanes and priority rules of the road.

Public transit is much more energy efficient that automobile use. At current occupancy rates of commuter autos, for instance, transit buses and light rail vehicles need to operate at only 12 percent average capacity to use the same amount of energy, and they are two-to-three times less energy intensive than automobiles on a seat per kilometer basis. During peak rush hours, when public transit operates at near or above seating capacity, the energy efficiency of public transit is even more dramatic. For instance, auto commuters originating in Surrey use 10 times more energy per person than those commuting by public transit.

The following exhibit illustrates the energy requirements by various modes of travel. A single-person automobile requires 4.16 megajoules of energy per passenger kilometre (a fuel consumption rate of about 12 litres of fuel per 100 kilometres). A light rail vehicle requires only 2.5 kilowatt-hours per kilometer or 0.36 megajoules per passenger-kilometre. A diesel bus requires about 50 litres of fuel per 100 kilometres or about 19.34 megajoules per kilometre (1 litre of diesel fuel contains 38.68 megajoules of energy). With an average load of 37 passengers in the rush hours, the energy efficiency is 0.52 megajoules per passenger-kilometre.



3. Transit and Air Pollution

Clean fresh air is a mixture of water vapour and gases (about 78% nitrogen and 21% oxygen plus small quantities of carbon dioxide, argon and several other gases) with tiny suspended particles like droplets of water and snow, salt crystals, pollen, etc. Man's activities have changed the composition of the air, especially in urban areas, by altering the concentration of 'natural' gases and introducing new substances. Often the result is what we know as air pollution.

Air pollution has been defined as the presence in the outdoor atmosphere of one or more air contaminants in such quantity and duration and under such conditions that may cause discomfort to or endanger the health, safety and welfare of people, or that may cause injury or damage to plant or animal life or property, or that interferes unreasonably with the normal enjoyment of life or use of property or conduct of business.

Air pollution affects man and his environment in various ways: as a hazard to human health; as a threat to vegetation; by altering climatic conditions; by damaging man-made materials and property; by creating hazards, poor visibility, in particular; by generating additional costs to repair resulting damage and to prevent adverse effects; and by diminishing aesthetic, recreational and other environmental amenities. Consumption of fossil fuels in transportation produces nitrogen oxides, hydrocarbons and carbon monoxide, all of which contribute to the formation of urban smog and/or acid rain. Carbon dioxide, methane, nitrous oxide and chloro-fluorocarbons are also produced, contributing greenhouse gases to the global atmosphere, with significant and far reaching effects on natural ecosystems and human activities.

TYPES OF AIR POLLUTION

A large number of chemical compounds and gases contribute to air pollution at the local, regional and global levels. The table on the opposite page summarizes the sources and effects of the five most common air pollutants in Canada:

- **Hydrocarbons.** These are unburned chemicals in combustion, such as car exhaust, which react in air to produce smog. Hydrocarbons have produced cancer in animals and many be a cancer-producing element in cigarette smoke. They are primarily of concern because of their role in the formation of photochemical oxidants.
- **Carbon monoxide.** This poisonous gas from the internal combustion engine drives out the oxygen in the bloodstream. A high concentration over a short exposure time can kill; a small amount can cause dizziness, headaches, fatigue, and slow driving reactions. Moderate concentrations often exist in tunnels, garages, and heavy traffic. It is especially dangerous for people with heart disease, asthma, etc.
- **Carbon dioxide.** A product of energy use in transportation (about 25 percent) and other sectors, is a greenhouse gas contributing to the warming of the climate with detrimental effects on agriculture.
- **Nitrogen oxides.** A result of burning fuels that convert nitrogen and oxygen to nitric oxide (NO) the greatest toxic potential is the tendency of nitric oxide (which is not an irritant) to oxidize to nitrogen dioxide (NO_2), which at high concentrations acts as a pulmonary irritant and is a major component of smog.
- **Sulphur oxides.** The primary source of these pollutants are factories and power plants burning coal or oil containing sulphur, which forms sulphur dioxide. This pollutant by itself is usually not harmful, but when it is mixed with other pollutants and with moisture, it irritates the eyes, nose, and throat, damages the lungs, kills plants, rusts metals, and reduces visibility.
- **Particulate matter.** Smoke, fly ash, dust, fumes, etc., are solid and liquid matter in air. They may settle to the ground or may stay suspended. They soil clothes, dirty window sills, scatter light, and carry poisonous gases to the lungs. They come from autos, fuels, smelters, building materials, fertilizers, etc.

Missing from the chart are several pollutants that are also significant. **Photo-chemical oxidants** are the chemical compounds (chiefly ozone, which is a powerful oxidizing agent and can adversely affect crops) that form the main components of smog which may result when hydrocarbons and nitrogen oxides are exposed to sunlight. **Heavy metals** such as lead, cadmium, mercury and arsenic have recently caused concern and has resulted in the push for lead-free gasoline. **Fluorides** contaminate plants while fluorocarbons pose a long-term threat to the protective ozone layer in the atmosphere. **Pesticides**, long the target of environmentalists, are always a concern. Finally, **odorous compounds**, such as hydrogen sulfide, create considerable nuisance problems in populated areas.

Principal Air Pollutants

Exhibit 10

Pollutant	Major Sources	Effects
Hydrocarbons: Compounds of hydrogen and carbon. Major pollutants result from incomplete combustion and evaporation of fuels and industrial solvents. Exists in air primarily as gases (methane, ethylene, acetylene, etc.). Benzopyrene is a solid particulate.	Most (approximately 85%) emitted from natural sources (vegetation, bacterial decomposition of organic matter). Major man-made source is processing, marketing and use of petroleum. Vehicle exhausts are prime sources; also waste incineration. Benzopyrene is found in tobacco smoke.	**Humans:** Most hydrocarbons toxic only at high concentrations. Some, including benzopyrene have produced cancer in animals (one study found that breathing city air is equivalent to smoking 7 to 36 cigarettes per day). Even low concentrations and certain hydrocarbons react with sunshine to produce smog.
Carbon monoxide: Colourless, odourless, tasteless gas, about 97% as heavy as air.	Gasoline-powered motor vehicles (about 2/3 of total emissions). Also industrial (e.g. petroleum refining) and burning.	**Humans:** CO entering bloodstream interferes with ability of blood to transport oxygen, impairing nervous system. At high concentrations, kills quickly. Concentration of 100 ppm, possible in heavy traffic, can cause dizziness, headache, lassitude, other symptoms of poisoning; can be a traffic hazard. 30 ppm for 8 hours or 120 ppm for 1 hour can be serious health risk to sensitive people (with heart disease, asthma, for example).
Carbon dioxide: Colourless, odourless, tasteless and nontoxic gas at standard conditions.	Gasoline-powered motor vehicles (about 1/4 of total emissions). Also industrial (e.g. electricity generation)	**Humans:** Although nontoxic, the gas causes suffocation due to lack of ample oxygen. **Other:** Carbon dioxide is a major contibutor to potential global warming. It accounts for about half of the projected greenhouse effect. CO_2 has been monitored since 1958 and has increased from 315 parts per million to about 350 parts per million.
Nitrogen oxides: Compounds of nitrogen and oxygen: Nitric oxide (NO) is a colourless gas, relatively harmless but convertible to: Nitrogen dioxide (NO_2) which is a gas, normally brownish-red in colour. In presence of sunshine, can act as a trigger for photochemical reactions resulting in smog.	Fuel combustion. About half from transportation fuels, particularly auto gasoline. Also, burning of fossil fuels for space heating and electric power generation.	**Humans:** Poorly understood. 13 ppm may cause eye and nose irritation. Higher concentrations indicate lung damage in animals. Easily transformed into NO_2 which is a pulmonary irritant and many produce inflammation of the lungs at high concentrations. **Plants:** Nitrogen oxides restrict plant growth; injuries similar to SO_2.
Sulphur oxides: Chemical compounds of sulphur and oxygen, principally: Sulfur dioxide (SO_2) is a colourless gas with pungent, irritating odour at concentrations of above 3 ppm. Sulphur trioxide (SO_3) is a gas, which combines with water in the atmosphere to form sulphuric acid.	Burning of sulphur-bearing fuels, such as coal and oil, for space heating and power generation. Also, industrial processes, especially petroleum refining and non-ferrous smelters.	**Humans:** SO_2 alone can irritate upper respiratory tract, if absorbed on particulate matter or converted into H_2SO_4, can be carried deep into the lungs where it can injure delicate tissue. Prolonged exposure to low levels of SO_2 has been associated with increased deaths due to cardiovascular disease in older persons. Higher levels may produce increased deaths due to respiratory diseases and complaints of cough, mucous membrane irritation. **Plants:** Sulfur oxides damage trees and other plants, especially grains, alfalfa, grapes, white pine, apples. **Other:** Also attack and destroy building materials including steel, zinc, paints, nylon and stone. High concentrations coupled with high humidity reduce visibility and create sulphuric acid.
Particulate Matter: Any matter, liquid or solid, dispersed in the air with individual particles smaller than 500 microns (about 1/50 of an inch) diameter. May remain airborne from a few seconds to months. Includes aerosols, visible particles, fumes, soot.	Plants generating electric power. Industries. Fires. Automobile exhaust (particles include lead); diesel vehicles are particular offenders (10 times as much particulate matter per gallon as gasoline-powered vehicles).	**Humans:** Some particulates are potentially poisonous or disease-producing (e.g., arsenic, asbestos, fluorides, lead). Others multiply potential harm of irritant gases (e.g., SO_2 absorbed on particulate matter will penetrate deeper into the lungs and damage tissue). Still others speed chemical reactions in the atmosphere, producing much more harmful substances (e.g., acid rain).

Source: adapted from Reg Lang and Audrey Armour. Environmental Planning Resourcebook. Prepared for the Lands Directorate, Environment Canada, 1980. pp 57.

SOURCES OF AIR POLLUTION

In the Province of British Columbia

Environment Canada has carried out periodic nation-wide inventories of atmospheric emissions of a number of air contaminants (2). The 1980 emissions inventory data for the Province of British Columbia for hydrocarbons, carbon monoxide, nitrogen oxides, sulphur oxides and particulate matter are summarized in the exhibit on the opposite page, which gives total emissions for each contaminant as well as the percentage contribution from major categories and major sources.

The total amount of air contaminants released into the atmosphere in British Columbia in 1980 was 2,924,699 metric tonnes. The main source of air pollution is the combustion of fossil fuels, especially by automobiles and various industrial processes. Other notable sources include coal mining, petroleum refining, pulp and paper manufacture, natural gas processing, aluminum production and saw mills.

An estimated 255.3 thousand tonnes of hydrocarbons were released in 1980 and the major contributors were gasoline motor vehicles and the coal industry. Transportation contributes 53.1 percent of the 1.88 million tonnes of carbon monoxide a year, mainly by automobiles. Slash burning is also a major contributor to carbon monoxide emissions. The most significant sources of the 167.0 thousand tonnes of sulphur dioxide were the coal industry, mining and rock quarrying and sulphate (kraft) pulping. The largest contributors of the 198.4 thousand tonnes of nitrogen oxides were diesel engines, gasoline motor vehicles, industrial fuel combustion and railroads. An estimated 419.5 thousand tonnes of particulate matter were released, of which 67.0 percent came from industrial sources.

Looking at the total amount of air pollutants by source sector, it is noted that transportation contributed 43.8 percent or 1.28 million of the 2.92 million tonnes. Industrial processes contributed 22.1 percent, fuel combustion 2.5 percent, waste incineration 9.1 percent, and miscellaneous, including slash burning, contributed 22.5 percent. Diesel-powered engines contributed 3.9 percent or 114,752 tonnes.

Not all pollutants, however, present the same danger to the environment. The following severity factors were used as a measure of the relative toxicity of the pollutants and to assess the contribution of each source: carbon monoxide - 1, hydrocarbons - 60, nitrogen oxides - 100, sulphur oxides - 120, particulate matter - 133. This classification is not completely reliable, mainly because too little is known of the inter-dependence of individual pollutants. It does, however, provide a rough indication of the relative danger to man of the pollutants. Using these factors, the contribution of pollution from transportation decreases to 22.7 percent and industrial processes increases to 51.6 percent.

Sources of Air Pollutants in British Columbia

Exhibit 11

Pollutant	Emissions (thousands of tonnes)	Major Contributors by Category		Major Contributors by Source	
		Category	%	Source	%
Hydrocarbons	255.3	Industrial Processes	30.6	Coal industry	20.5
				Petroleum refining	4.4
				Sulphate pulping	2.3
		Transportation	40.3	Gasoline motor vehicles	30.4
				Diesel-powered engines	2.9
		Miscellaneous	21.0	Gasoline/diesel marketing	6.7
				Applied surface coatings	6.4
				Slash burning	3.7
Carbon Monoxide	1,884.4	Industrial Processes	8.0	Petroleum refining	4.5
				Primary aluminum	2.0
				Sulphate pulping	1.5
		Transportation	53.1	Gasoline motor vehicles	44.6
				Off-road gasoline use	4.4
				Aircraft	1.8
				Diesel-powered engines	1.1
				Marine	0.9
		Miscellaneous	26.4	Slash burning	26.4
Nitrogen Oxides	198.4	Transportation	77.0	Diesel engines	37.3
				Gasoline motor vehicles	29.2
				Railroads	5.8
		Fuel combustion	12.5	Industrial fuel combustion	7.6
				Residential fuel combustion	1.8
				Power utilities	1.5
Sulphur Oxides	167.0	Industrial Processes	74.7	Natural gas processing	38.1
				Sulphate pulping	6.6
				Primary copper & nickel	5.1
				Primary aluminum	3.7
				Petroleum refining	3.5
		Fuel combustion	18.0	Industrial fuel combustion	14.2
				Commercial fuel combustion	1.8
				Residential fuel combustion	1.8
				Power utilities	0.1
		Transportation	7.2	Diesel-powered engines	4.3
				Gasoline motor vehicles	1.5
				Marine vessels	1.0
Particulate Matter	419.5	Industrial Processes	67.0	Coal industry	19.0
				Mining and rock quarrying	15.9
				Sulphate pulping	12.1
				Sawmills	8.6
				Primary aluminum	2.2
				Asbestos production	2.0
				Asphalt production	1.4
		Fuel combustion	1.6	Industrial fuel combustion	1.1
				Fuel wood combustion	0.3
		Transportation	3.2	Gasoline motor vehicles	1.3
				Diesel-powered engines	1.3
		Miscellaneous	23.6	Slash burning	23.3

Open sources such as agricultural tilling, unpaved roads, etc. contribute significantly to emissions of particulate matter; similary, forest fires are important contributors to emissions of hydrocarbons and particulate matter. These sources have been excluded because the focus is on man-made sources that could be important to urban pollution.

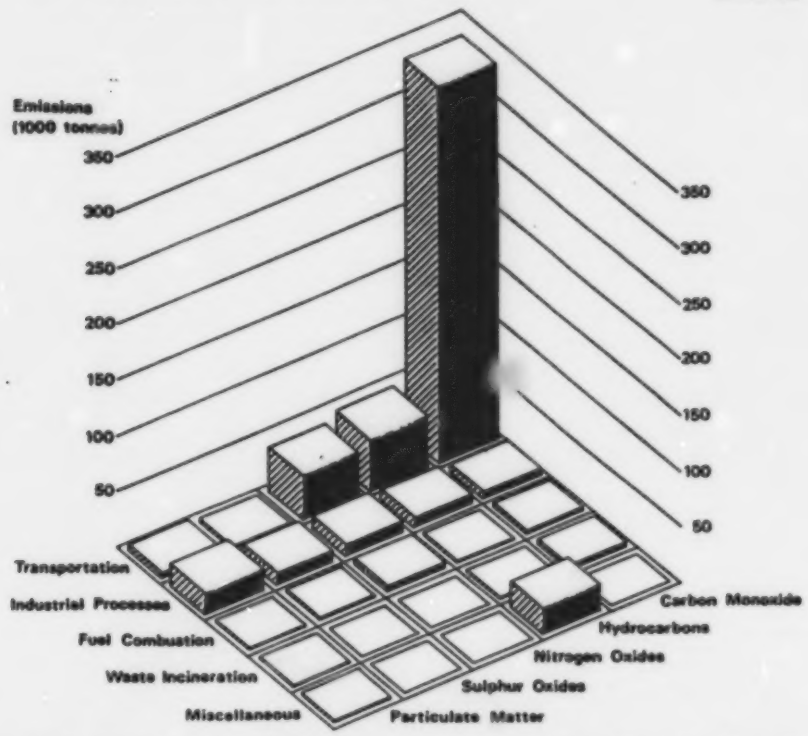
Source: Environment Canada, Emissions and Trends of Common Air Contaminants in Canada: 1970 to 1980. Publication Number EPS 7/AP/17, September 1986.

SOURCES OF AIR POLLUTION (cont'd)

In the Greater Vancouver Regional District

In the Greater Vancouver Regional District, an inventory of air emissions by major source sector was developed in 1985 by the Pollution Control Division and the results are summarized in the following exhibit.

Emissions by Source Sector in the Regional District *Exhibit* 12



Source: Adapted from *GVRD Air Management Plan– Stage 1: Assessment of Current and Future Air Quality*, Greater Vancouver Regional District, Burnaby, B.C., September 1989, p.4-4.

Hydrocarbon emissions from light duty vehicles account for 47 percent of the total emitted, making it the largest subsector source. Hydrocarbon emissions from transportation sources originate principally from the tailpipe and fuel evaporation. The second largest subsector source of hydrocarbons is the natural emissions, principally trees, which emit isoprene and terpene. The third ranked source, referred to as "other area sources", result from evaporation of solvents used for surface coatings, general purpose cleaning and dry cleaning, and contribute 10 percent of the total. The top five ranked source subsectors account for 81 percent of the total for the GVRD.

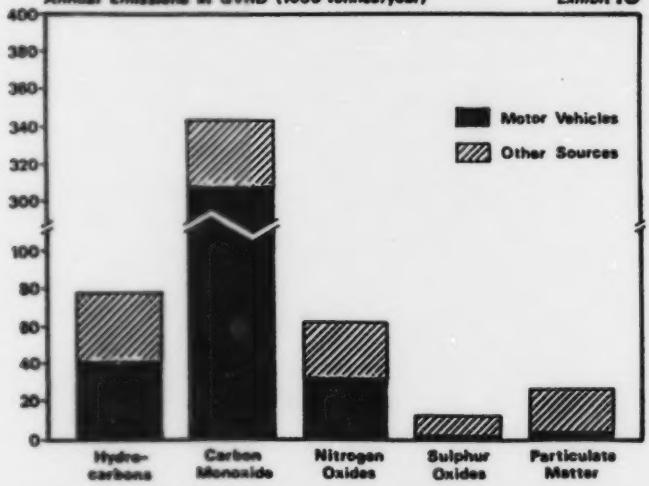
Carbon monoxide emissions result primarily from incomplete fuel combustion. Consequently, the main sources of carbon monoxide are light duty and heavy duty vehicles, which emit 90 percent of the total for the GVRD. Other notable sources of carbon monoxide emissions are solid waste incineration and the mineral, petroleum and chemical industries.

The main sources of nitrogen oxides are motor vehicles. The four highest ranked subsector sources emit 79 percent of the total nitrogen oxides in the GVRD. The non-metallic mineral industry is a major source of nitrogen oxides because it includes several cement manufacturing facilities.

The refined petroleum industry, the non-metallic mineral industry, heavy duty vehicles and light duty vehicles emit 86 percent of the total sulphur oxides in the GVRD. Vehicle sources emit sulphur oxides because of sulphur present in gasoline and diesel fuel at levels of 0.03 percent by weight and 0.22 percent by weight respectively. The remaining sulphur oxides originate from a large number of subsectors.

Mobile vehicles are the predominant source of particulate matter. The wood industry is second in order of rank as a source of particulate emissions, with those occurring from permitted sources. The major contributor to particulate matter emissions from transportation is road dust from paved roads. If road dust (94,902 tonnes) is excluded from the total for particulate emissions, the sector total decreases to 4,685 tonnes, second in rank to industrial processes. The total particulate emissions, excluding road dust from paved roads is 26,231 tonnes. Exclusion of road dust, which is one component of particulate emissions from mobile sources, results in the wood industry being the largest source of particulate matter.

Motor Vehicle's Contribution to Air Pollution
Annual Emissions in GVRD (1000 tonnes/year) *Exhibit* 13



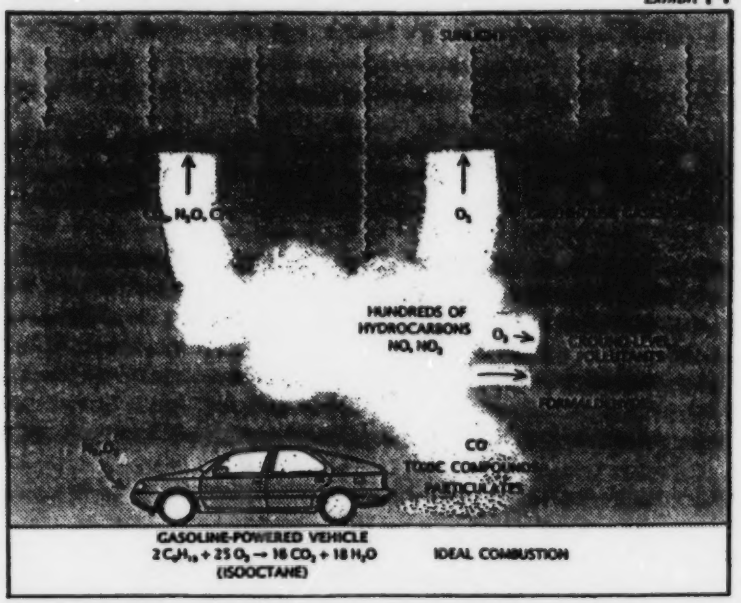
Source: *GVRD Air Management Plan - Stage 1: Assessment of Current and Future Air Quality*, Greater Vancouver Regional District, Burnaby, B.C., September 1989, p. 4-4.

In total, road vehicles contribute 75.9 percent of all emissions. They contribute 53.3 percent of the hydrocarbons, 89.5 percent of the carbon monoxide, 64.2 percent of the nitrogen oxides, 17.0 percent of the sulphur oxides and 14.8 percent of the particulate matter, as illustrated in the exhibit opposite.

VEHICLE EMISSIONS — TYPE

The principal pollutants emitted in the exhaust gases of gas and diesel engines are: carbon monoxide, unburnt hydrocarbons, partial oxidation products, oxides of nitrogen, oxides of sulphur, lead derivatives, solid or liquid particles in smoke, and some ill-defined constituents characterized by their smell (aromatic hydrocarbons, aldehydes and sulphur compounds).

Chemical Reactions in the Motor Vehicle's Exhaust *Exhibit* 14



Source: Adapted from C.L. Gray and J.A. Alson, *The Case for Methanol*, Scientific American, November 1989, p. 111.

Carbon Monoxide

Carbon monoxide is certainly the best known pollutant, and it is the pollutant most representative of the level of pollution from internal combustion engines. The quantity of carbon monoxide contained in engine exhaust gases is substantially greater than the concentrations which ought to be encountered on the basis of the chemical equilibrium conditions, which are characterized by the reaction: $CO + OH \rightleftharpoons CO_2 + H$. Although the temperature rise in an engine may be some 50°C per millisecond, this rate of increase is sufficient to impede completion of the above reaction, even when sufficient OH radicals are present.

In the gas engine, since the fuel is a hydrocarbon mixture (a complex combination of about 15% hydrogen and 85% carbon by weight) and since combustion takes place in the presence of oxygen, only water vapour and

carbon dioxide ought to exist in the exhaust. In practice, however, this is not the case. To obtain clean gases, the mixture fed into the engine cylinders would have to have a stoichiometric fuel/air weight ratio (heptane C_7H_6 = 1 gram fuel/15.3 grams of air).

Experience, however, shows that it is impossible for an engine to operate properly without an excess of fuel and with a mixture of constant richness. In the cases of the diesel engine, with which almost all buses are equipped, the process of combustion takes place with an excess of air, and the quantities of carbon monoxide are considerably smaller than those emitted by the gas engine.

Carbon Dioxide

Carbon dioxide, until very recently, was believed to be an innocuous product of the combustion process and, therefore, very little attention was focused on this gas and very little was known about it.

Now, however, it is known that continued emissions of CO_2 and other 'greenhouse' gases (CH_4 and N_2O) are expected to cause substantial global warming with adverse consequences for agriculture and coastal cities. Total 1988 emissions of carbon dioxide in Canada are estimated in the order of 473 megatonnes. Transportation energy use accounts for about 25 percent of total CO_2 emissions. According to Environment Canada, the automobile contributes 268.62 grams of CO_2 per kilometer of travel.

Unburnt Hydrocarbons

The emission of unburnt hydrocarbons is also a consequence of the phenomena described in the previous paragraphs. The hydrocarbons making up the fuel are mainly cracked in the cylinders of spark-ignition engines, whereas they undergo considerable partial oxidation in diesel compression-ignition engines.

In addition to the light unburnt hydrocarbons normally contained in the fuel, there are about a hundred substances deriving from modifications of the hydrocarbon chains due to incomplete combustion, cracking and polymerization. The typical product is 3,4-benzopyrene. Recent experiments suggest that benzopyrene appears in diesel exhausts only when the emissions are highly opaque owing to severely maladjusted injection.

Oxides of Nitrogen

The exhaust gases of internal combustion engines contain small quantities of oxides of nitrogen, whose concentrations generally lie in the range 100-5,000 ppm depending on the type of engine and operating conditions. In the diesel engine, reduction of black smoke by excess air admitted to the cylinder tends to favour the formation of oxides of nitrogen.

These oxides of nitrogen play a very important part in atmospheric pollution, firstly because of their intrinsic toxicity, but also on account of their high reactivity with other substances also originating from exhaust gases, e.g. unburnt hydrocarbons and aldehydes. Hence the oxides of nitrogen are at the root of the majority of problems of air pollution due to internal combustion engines. During combustion and at the actual instant of exhaust, nitric oxide is practically the only representative of this group. But immediately upon discharge into the atmosphere, oxidation of NO into NO_2 is favoured by cooling of the gases and the presence of atmospheric oxygen. NO_2 then forms nitrous and nitric acids and addition and substitution products with the unburnt hydrocarbons and aldehydes also discharged in the exhaust gases.

Oxides of Sulphur

Sulphur dioxide SO_2, which is highly toxic and highly irritant, may occur in exhaust gases when the fuel contains a high proportion of sulphur. Vehicles today generally use de-sulphurized fuels whose specifications stipulate very low sulphur contents (0.45 - 0.55%). Hence the inherent harmfulness of the very small quantities of sulphur dioxide emitted by buses is minimal, and does not constitute a significant problem.

Lead Derivatives

These are the organic derivatives of lead: tetraethyl lead $Pb(C_2H_5)_4$ and tetramethyl methyl lead $Pb(CH_3)_4$, which are added to gasoline mainly to improve the octane number. This problem of lead is therefore specific to the gas engine and is not applicable to the diesel.

Aldehydes

In the combustion of hydrocarbons, when the oxygen/hydrocarbon ratio varies outside the normal limits, combustion is incomplete, and at about 400°C a form of transient partial oxidation giving rise to aldehydes may occur; for instance, methane at 400°C can give rise to formaldehyde. The formation of aldehydes in diesel engines is generally small. However, some direct injection engines emit sufficient aldehydes to create a nuisance. The aldehyde concentration may also be considerably increased if lubricating oil is able to enter the combustion chamber (in worn engines, giving blue exhaust smoke).

Aldehydes coexist in gases in various molecular structures: straight-chain aliphatic aldehydes or aromatic nucleus aldehydes; the most common are formaldehyde, the first member of the aliphatic series, and acetaldehyde, ethylenic aliphatic aldehyde or acrolein. Total aldehydes are conventionally expressed as formaldehyde. The maximum quantity that can be produced by a diesel engine under unfavourable running conditions is approximately 100 ppm.

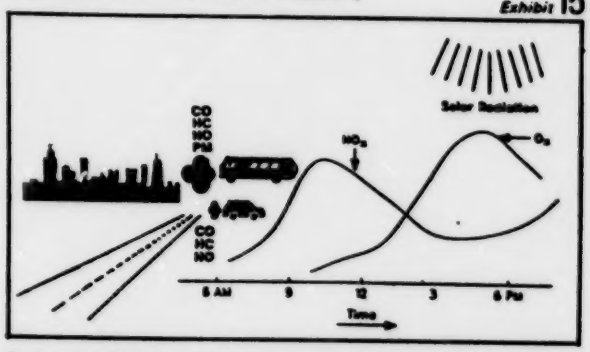
VEHICLE EMISSIONS - FACTORS

Time of Day as a Factor in Pollution Levels

Pollution levels vary considerably depending on the type of vehicle operation, the time of day, and the atmospheric conditions within the urban area. The exhibit below is a simple illustration of the complex process of nitrogen oxides and ozone chemical reactions. This figure is intended to convey some of the complexities of the process in general and of the situation of buses in particular. First, the concentration of nitrogen oxide emissions from buses is greater in the downtown area than in the suburbs. In the immediate vicinity of buses and other vehicles, the emissions of nitrogen oxides actually scavenge ozone molecules, thereby reducing nearby ozone concentrations. As the nitrogen oxides disperse into the surrounding mass of air, it moves along with the air mass and 'cooks' with solar radiation, ultimately increasing the amount of ozone in the atmosphere. Because this interaction with sunlight takes some time to occur, peak ozone concentrations tend to occur in the afternoon and downwind in the suburbs.

Chemical Reactions Near a Roadway

Exhibit 15



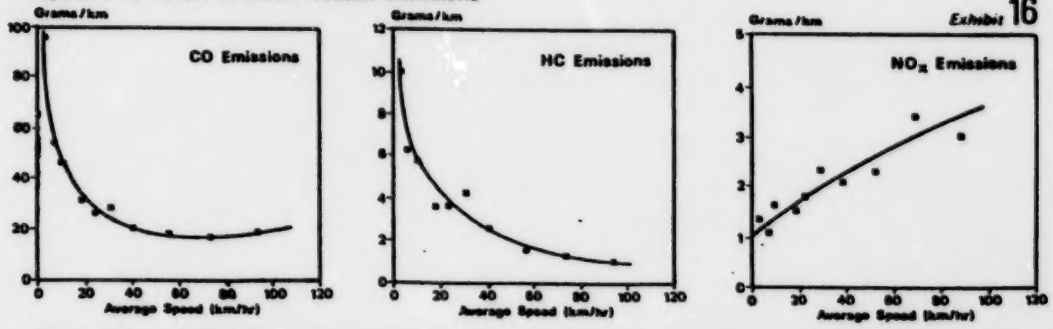
Source: D.J. Santini and J.J. Schiavone, *Technical Problems and Policy Issues with the 1991 Bus Emission Standards*, Transportation Research Record 1164, Washington, D.C., 1988, p. 7.

Speed as a Factor in Emissions

A number of studies have illustrated the effect of speed on motor vehicle emissions and there is a considerable difference in arterial and expressway

Speed as a Factor in Motor Vehicle Emissions

Exhibit 16



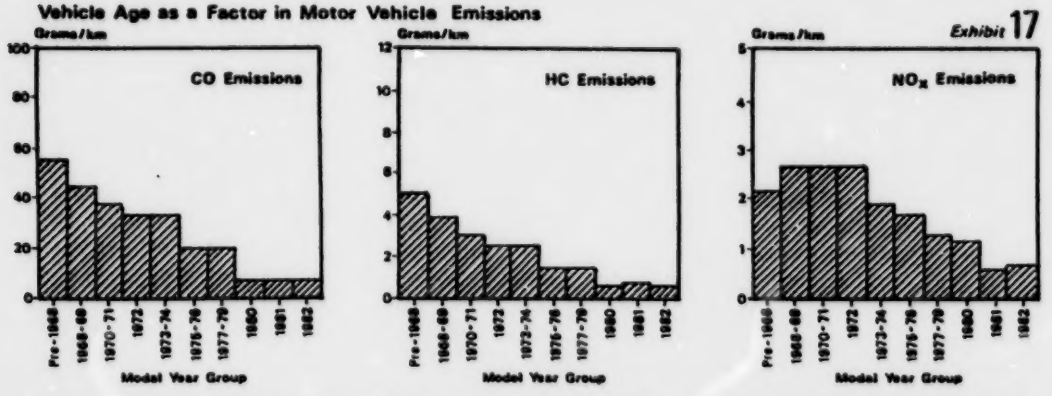
Source: R. Joumard, *Real Exhaust Gaseous Emissions and Energy Consumption from the Passenger Car Fleet*, SAE Paper 881764, Warrendale, PA, 1988.

carbon monoxide concentrations. Stopping and starting (for example, on a major signalized arterial street) have a very dramatic effect on hydrocarbon and carbon monoxide emissions from vehicles. The following exhibit illustrates the emissions of carbon monoxide and hydrocarbons of an automobile at various speeds. Contrary to the declines in emissions for hydrocarbons and carbon monoxide, emissions for nitrogen oxides increase with increasing speed. A recent study investigating de-forestation along expressways in Germany recommended reduced speed limits in order to limit the amount of pollution affecting the trees (to 100 km/h). In North America, these emissions, however, are generally reduced by the recirculation of the exhaust gas through the carburetor.

Vehicle Age as a Factor in Emissions

Vehicle age is a factor in the level of pollution primarily because of innovations in anti-pollution equipment rather than lack of maintenance.

Vehicle Age as a Factor in Motor Vehicle Emissions *Exhibit* 17



Source: M. Sabourin and L. Platte, *U.S. Light Duty Vehicle Fleet Emissions Performance and the Emissions Impact of Technology Changes*, SAE Paper 881681, Warrendale, PA, 1988.

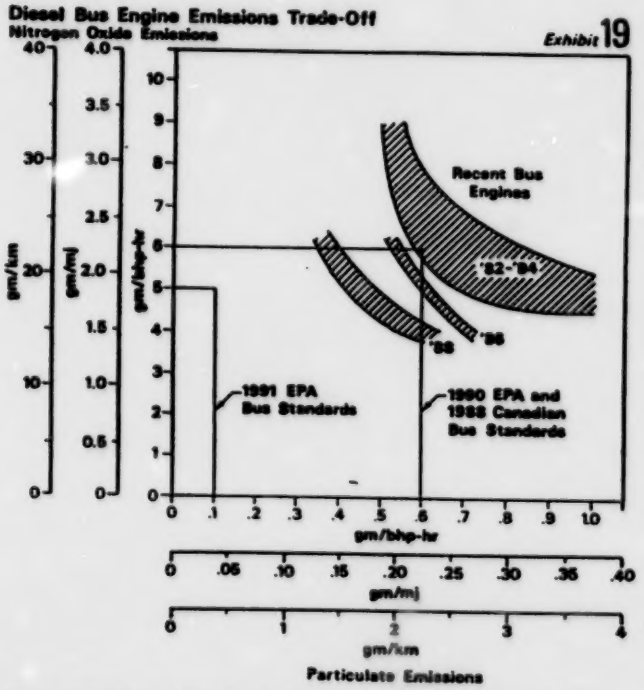
Diesel Bus Engine Emissions Trade-Off

There has been considerable concern in the transit industry lately over emission standards for diesel buses proposed by the United States Environmental Protection Agency. These standards, shown in the exhibit opposite, have also been proposed for application in Canada. New technology combined with an emissions strategy is required to meet these future standards without sacrificing performance, fuel consumption, durability, reliability.

Diesel Bus Engine Emissions Standards *Exhibit* 18

Model Year	EPA Emission Limits (gm/bhp-hr)			
	HC	CO	NO_x	PM
1988	1.3	15.5	6.0	0.60
1990	1.3	15.5	5.0	0.60
1991	1.3	15.5	5.0	0.10
1994	1.3	15.5	5.0	0.10
	Proposed Canadian Emission Limits (gm/mj)			
1988	0.48	5.77	2.20	0.22

The major concern for urban bus manufacturers is the trade-off between nitrogen oxides and particulate emissions. Diesel engine nitrogen oxides and particulate emissions follow a classic trade-off curve as shown in the exhibit follwing. Generally as nitrogen oxides are reduced, particulates are increased and vice versa. Significant progress has been made in the 1980s in shifting this relationship so that lower particulates are emitted for a given level of nitrogen oxides. As combustion-generated particulates are lowered, the contribution by lubricating oil and fuel contaminants (for example, fuel sulphur) becomes a significant portion of the exhaust particulates. To meet the demanding requirements of 0.1 gm/bhp-hr for particulates (including deterioration factor, production tolerance variability, selective enforcement, etc.), the design target has to be lower than this level. Current technological developments suggest that this may not be feasible if diesel fuel is used in the engine, although Cummins suggest that they may have a turbo-charged engine which will meet the requirements.



Source: Adapted from V.K. Duggal, *Meeting Bus Emission Standards – A Perspective*, Transportation Research Record 1164, Washington, D.C., 1988, p. 41.

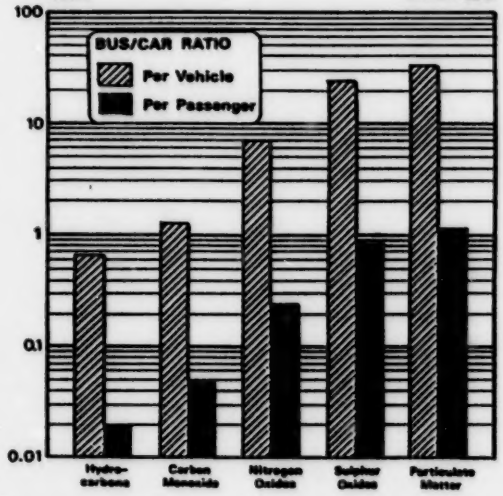
Technologies for aftertreatment of particulates are being developed for the Detroit Diesel engines. These require collection of particulates in a trap and their controlled oxidation or regeneration. The reliability and durability of trap systems have yet to be demonstrated. These systems also increase engine costs and add a fuel consumption penalty. Trap technologies may not be feasible for 1991 buses.

Some alternative fuels exhibit particulate emissions characteristics that make them attractive for use in heavy-duty engines. These include natural gas, methanol, and propane. Methanol is of particular interest in urban transit. The efficiency of methanol heavy-duty engines is similar to that of diesel engines because the principle of operation (direct injection of fuel, high compression ratio, and unthrottled) is preserved.

VEHICLE EMISSIONS - QUANTITY

When vehicle emission levels are compared, it is evident that a bus pollutes significantly more than an automobile -- seven times the nitrogen oxides, 25 times the sulphur oxides, and 34 times the particulate matter. The most significant benefit of the bus, however, is its ability to replace fifty or so cars on the road; hence, air pollution is reduced by ten to twenty-five times. On a passenger-kilometre basis during peak travel periods in Vancouver, transit buses produce 1/4 the amount of nitrogen oxides, 1/22 the amount of carbon monoxide, and 1/50 the amount of hydrocarbons that automobiles tend to produce; production of sulphur oxides and particulate matter on a passenger-kilometre basis are about equal. Furthermore, light rail transit and trolley buses which run on electricity produce only negligible amounts of these pollutants at the source.

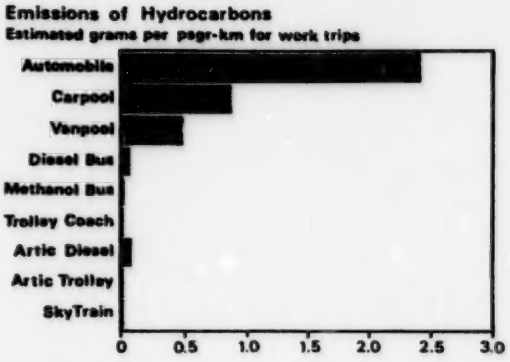
Bus/Car Emission Levels
Ratio
Exhibit 20

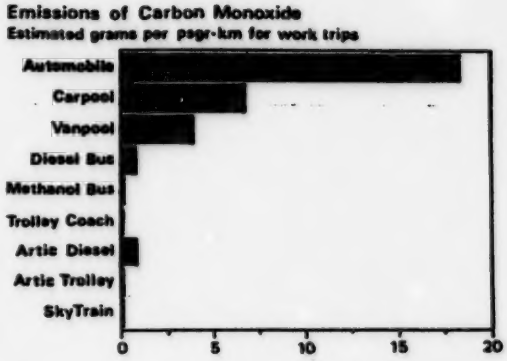


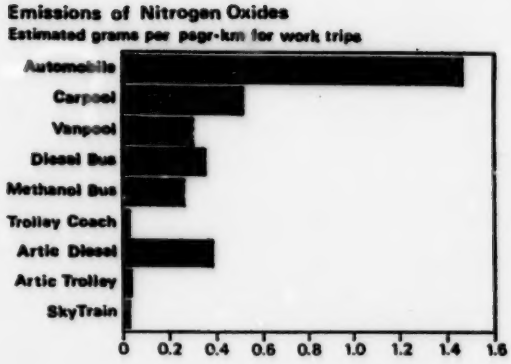
The exhibit opposite illustrates the hydrocarbon, carbon monoxide, nitrogen oxides, sulphur oxides and particulate emissions of automobiles, various types of bus and light rail vehicles. For each transit mode, the number of grams of pollutants per passenger-kilometer during peak operating conditions is shown (i.e., for work trips). The graphs indicate that when the automobile's performance is the worst (during peak travel periods), the urban bus performs best. In any case, both peak and non-peak automobile travel contribute far more pollution to the environment per passenger-kilometre than bus or rail vehicles.

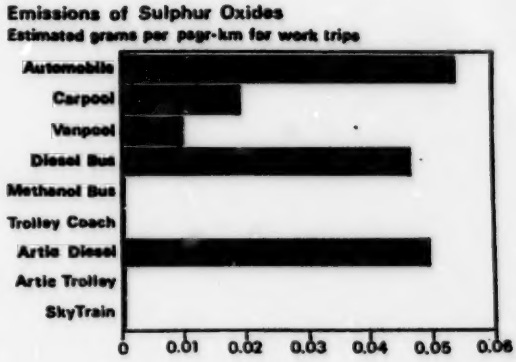
It is estimated that one person using mass transit for a year instead of using their automobile saves the environment, on average, about 13.5 kilograms of hydrocarbons, 99.5 kilograms of carbon monoxide and 7.0 kilograms of nitrogen oxides. Very little savings of sulphur oxides or particulate matter would accrue (only 12 to 14 grams). If electric vehicles (trolley or SkyTrain) are used, the savings are considerably more.

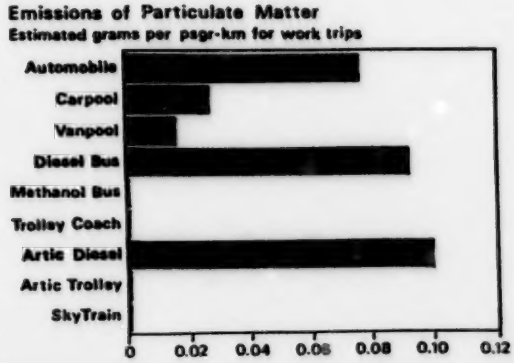
Within the transit industry, as in the auto sector, initiatives have been undertaken to control the emission of pollution particulates from transit vehicles; but, the potential for improved urban air quality clearly lies in the ability of transit to transport large numbers of people in a single vehicle, the same principle which results in significant energy savings.











Emissions by Mode of Travel and Type of Pollutant *Exhibit* 21

4. Transit and Noise Pollution

Noise probably ranks equally with air pollution in the forefront of nuisances accompanying the development of the urban environment.

It is a major environmental factor, and its growth in large urban areas inevitably leads to a decline in the quality of life. Since noise is inherent in human activity, it is not a new problem. Noise has always been associated with towns, and in days of old citizens complained of the din and clatter of horsedrawn traffic in the cobblestone streets.

In the sense which concerns us here, and from the subjective view point, noise for a given individual is an unwanted acoustic phenomenon or sound. Noise may also be described as a secondary effect of a personal action having unpleasant repercussions on third parties not participating in the action and not deriving any direct benefit from it. Housing continues to be built next to heavily travelled roads, however, as many people appear willing to trade off noise levels for improved accessibility.

There are still gaps in our knowledge of the consequences of noise on the physiological and psychophysiological state of persons exposed to it. Physically, noise is a phenomenon connected with the vibration of air molecules, whose spectrum differs greatly from those of pure sounds or musical notes and as a rule contains a high proportion of random components. In practice, it is essentially a subjective phenomenon. The problem of noise is bound up with individuals and their sensations and is defined more by human values and ambient conditions than by precise physical measurements. The difficulty of measurement lies in the highly subjective nature of the effects of noise.

NOISE POLLUTION

Noise has often been described as unwanted sound, sound without value, or vibrational energy out of control. Generally, noise has three sources: (1) transportation noise, (2) occupational or industrial noise, and (3) community background noise. Although aircraft noises may first come to mind when transportation noises are being discussed, noise from surface vehicles, such as automobiles, trains, trucks, buses and motorcycles, and industrial and occupational noise from high-speed equipment are more widespread and more significant.

Typical Sound Sources

In this chapter, noise pollution is primarily related to surface transportation noise and comparisons with community noise levels. The exhibit below provides examples of typical sound sources. The sound levels illustrate the relative amounts of noise generated by selected sound sources as compared to human response and hearing effects.

Sound Levels and Human Response

Exhibit 22

	Noise Level	Human Response	Hearing Effects	Conversational Relationships
	150			
Jet carrier deck operation	140			
	130	Painfully loud Limit of amplified speech		
Jet take-off (200 ft) Auto horn (3 ft)	120			
Riveting machine Jet take-off (2000 ft)	110	Maximum vocal effort		
Shout (0.5 ft) Subway station	100			Shouting in ear
Heavy truck (50 ft)	90	Very annoying Hearing damage (8 hours)	Contribution to hearing impairment begins	Shouting at 2 ft
Pneumatic drill (50 ft)	80	Annoying		Very loud conversation, 2 ft
Freight train (50 ft) Freeway traffic (50 ft)	70	Telephone use difficult and		Loud conversation, 2 ft
Air conditioning (20 ft)	60	intrusive		Loud conversation, 4 ft
Light auto traffic (100 ft)	50	Quiet		Normal conversation, 12 ft
Living room Bedroom Library	40			
Soft whisper (15 ft)	30	Very Quiet		
Broadcasting studio	20			
	10	Just audible		
	0	Hearing threshold		

Source: *Noise Pollution*, U.S. Environmental Protection Agency, Washington, D.C., August 1972, p. 6.

Measurement of Noise

The measurement of noise and the correlation of that noise to human annoyance is a very complex procedure. Extensive research has been completed to quantify the most significant measures of loudness. Two approaches have been utilized: (1) research on how an individual judges loudness and noise from a psychological viewpoint and (2) experiments on groups of people in order to determine how they judge the acceptability of various sounds on category judgment scales.

There are many scales for measuring sound that incorporate psychologically derived measures and physical measures. Among the former are: Loudness, Loudness Level, Perceived Noise Level (PNdB), and the Speech Interference Level (SIL). Among the latter are Overall Sound Pressure Level (OASPL), and A-Weighted Sound Level (dBA).

It has been found by experience that the degree of auditory sensation perceived by the ear is not proportional to the instantaneous acoustic pressure but varies practically as the logarithm of this pressure; for this reason the unit of sound intensity adopted employs a logarithmic scale. This unit is the decibel. However, since the decibel does not correspond entirely to the response of the ear, the actual units used are the dBA and the DBB, which represent the subjective intensity of sounds by means of appropriate corrections: the DBA for low-level sounds and the dBB for moderate-level sounds.

Like pollution, noise is one of the concerns of our time, and these two nuisances have aspects in common. In both cases, one becomes habituated to the nuisance, whether it is polluted air or a relatively high background noise level; the physiological effects take their toll in the more or less long term. From another aspect, air pollution peaks constitute an instantaneous nuisance by virtue of unpleasant smells, and isolated high-level noises are painful.

The effects of noise on the individual may be grouped in three main classes, which are interconnected:

- subjective effects, manifested in such concepts as discomfort, annoyance, disturbances, din, etc.; these as it were represent the undesirable side of a noise;
- effects interfering with specific activities such as conversation, sleep, learning or the accomplishment of a task;
- effects having immediate or long-term physiological consequences.

These different categories are not mutually exclusive. Prolonged disturbance of sleep, for example, could be accompanied by physiological effects. Similarly, interference with speech can constitute a source of discomfort. Living near an airport can increase the stress level of individuals and result in long-term physiological effects.

URBAN TRAFFIC NOISE CHARACTERISTICS

In the urban environment, noises are numerous and varied, but motor traffic is generally the predominant source of acoustic nuisance.

In this report, we shall confine ourselves to mentioning some essential characteristics of noise, which is unfortunately particularly pernicious. Traffic noise is not continuous. As a vehicle approaches an observation point, the sound level increases, reaches a maximum, and then decreases as the vehicle recedes. The regular flow of traffic on a main road sets up a virtually constant rumble. Two aspects must therefore be considered with regard to the structure of the noise: peaks, and background noise.

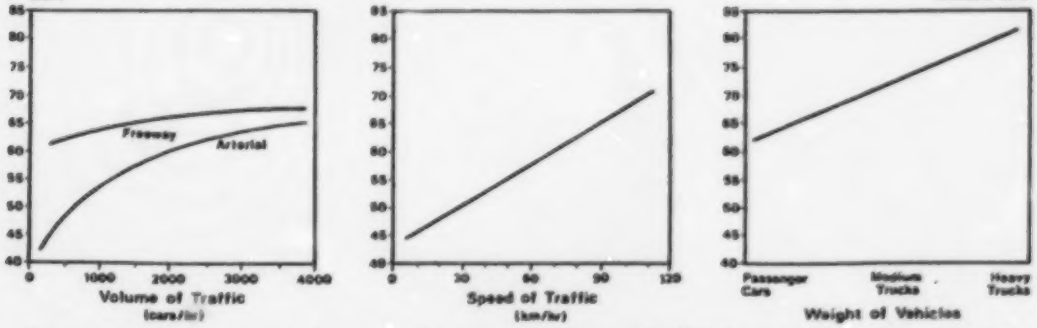
In general, the effects increase, on the one hand, with the average level and its rate of change, and on the other hand, with the level and number of noise peaks. With moderately heavy traffic the nuisance is generally well characterized by the average level, whereas when the volume of traffic is small, the peaks constitute the principal nuisance.

The factors affecting the sound level are: atmospheric conditions, traffic movements, natural screens, traffic speed, flow and density, driver behaviour, and the road (design, gradient, bends, type of surface, width, number of stop signs). We can not consider these factors in detail. It is noted only that studies have shown that acceleration of a vehicle can produce an increase of 10-20 dBA as compared with cruising in town.

Other interesting results: the average sound levels emitted by traffic in excess of 50 cars/hour increase by 3 to 5 dBA for every doubling of vehicle flow and by 4 to 6 dBA for each doubling of speed above 40 km/h. In general, the average sound level (the level exceeded for 50 percent of the time) increases as 10 log N (where N is the number of vehicles) on a freeway and as K log N (where K lies between 10 and 20) in conventional streets. These factors are illustrated in the following exhibit.

Effect of Traffic Characteristics on Sound Levels

Exhibit 23



Sources: Savary, Y., *Motorbus and Environment*, 40th International Congress of the UITP, Brussels, Belgium, 1973; and S. Parker, Editor, *McGraw-Hill Encyclopedia of Environmental Science*, McGraw-Hill, New York, N.Y., 1980, p.487.

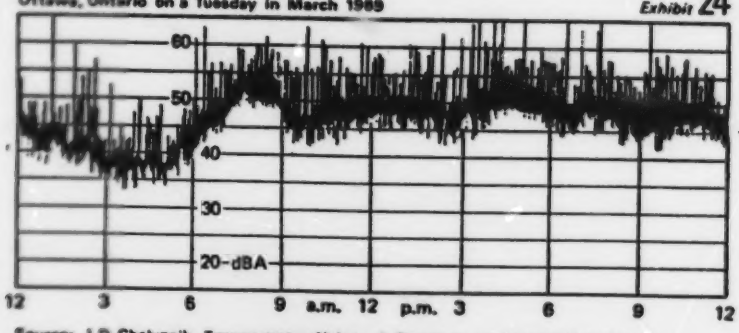
COMMUNITY BACKGROUND NOISE

Sound sources, when viewed in proper perspective, must be related to the prevailing community background noise level. Extensive research indicates that for each community there is a noise signature that corresponds to the type and spatial arrangement of industrial activities, transportation corridors, and land-use patterns within the region as well as atmospheric conditions and the topography.

A study of Ottawa, Ontario, attempted to develop a predictive equation to determine the background noise at any given point in the community. Recordings were made for four days at a location within a residential area but not adjacent to a freeway or major street. The exhibit shows the sound signature of the background noise levels for a Tuesday in March 1969. The average noise level was found to be 48 dBA during the daylight hours and 38 dBA at night for the location shown.

Community Background Noise Levels
Ottawa, Ontario on a Tuesday in March 1969

Exhibit 24



Source: J. D. Chalupnik, *Transportation Noises. A Syposium on Acceptability Criteria*, University of Washington Press, Seattle, 1970, p. 27.

The 8:00 am peak hour and the 5:00 peak hour are indicated with the am peak showing more prominently. Instantaneous peaks of 65 dBA were common throughout the daylight hours during the week with the mean level between 50 dBA and 55 dBA. This is contrasted to a mean noise level of from 45 dBA to 50 dBA on Saturday and Sunday.

Although community response to noise, especially highway-related noise, must certainly be negative, a certain amount of transportation noise is unavoidable. Quantifying objectionable transportation noise levels is difficult because of the extreme variability of human response to noise and, even more importantly, human response to sound.

It is probably true that low background noise is less objectionable than peak sounds that may occur, for example, when traffic is accelerating from a stop sign, when a bus is accelerating from a bus stop, or when a light rail vehicle is turning a particularly tight corner.

COMPARISON OF TRANSPORTATION NOISES

Transportation noise is one of the most prevailing sources of sound in the urban area. Much of the urban area background noise is composed of the aggregate sounds produced by the thousands of cars. trucks, airplanes, and other transportation modes in the urban area.

Measurements of various transportation sound sources provide the comparative data in the exhibit below. Many transportation noise sources are between 80 dBA and 100 dBA as measured at the operator's ear and fall to significantly lower levels at the average observer's distance. Trucks and buses have noise levels varying from 81 dBA to 96 dBA. this compares to aircraft noises for the operator of from 73 dBA to 119 dBA and outside noise levels of in excess of 110 dBA measured from a 400 foot altitude. Sound levels in the immediate vicinity of the aircraft may easily reach 160 dBA.

Public transit vehicles make noise, too. Noise levels for the public transportation facilities are based on current experience with equipment now in operation in Germany, England, Toronto and Calgary and are illustrated in the following exhibit. A range of noise levels from 78 dBA to 100 dBA, depending on the observer's location, the type of equipment, and the location (above ground or below ground) have been recorded. These noise levels are representative of most of the noises associated with existing public transit systems.

According to a recent report on SkyTrain noise reduction, SkyTrain vehicles generally emit no more than 74 dBA at a distance of 15 metres at full speed. This is equivalent to an average noise over 24 hours of 56 to 65 dBA depending on other ambient noise, such as traffic. For comparison, noise levels on the Montreal Metro, a system utilizing rubber tires on concrete, are generally in the range of from 60 dBA to 80 dBA.

Representative Transportation Noise Levels *Exhibit* 25

Type of Vehicle and Location	Typical Noise Levels	Relative Sound Intensity
Street (at curb), night, light traffic	40 ± 4	-
Diesel bus, idling at 6 metres	63 ± 4	.3
Street (at curb), night, heavy traffic	65 ± 4	.6
Trolley bus at 6 metres	69 ± 4	.9
Street with rough pavement, heavy traffic	70 ± 4	1
Automobiles at 6 metres	71 ± 4	1
Light trucks at 6 metres	72 ± 4	3
Light rapid transit at 6 metres	73 ± 3	5
Diesel bus, acceleration, curb pullout	78 ± 4	9
Diesel bus, acceleration, high gear	81 ± 4	10
Heavy truck, accelerating, heavy traffic	82 ± 5	30
Toronto subway trains at 6 metres	83 ± 3	48

Source: Adapted from *Noise Pollution - A Review of its Techno-Sociological and Health Aspects*, Biotechnology Committee, Carnegie-Mellon University, unpublished study, 1968 and M.D. Jackson et al., *Transit Bus Operations and Methanol Fuel*, SAE Paper 850216.

The exhibit shows that under given urban traffic conditions, the noise of a bus is equivalent to that of 9 to 10 private cars combined, and that a private car generally emits 10 dBA less than a bus. With an increase in the proportion of buses from 10 to 30 percent, the average noise level rises by 5 dBA, or more on gradients. These unfavourable results from the bus are due to the diesel engine, which is a noisier power source than the gasoline engine although it is cleaner as regards pollution. The benefit of the bus, and other transit vehicles, is that it can seat many more people and therefore reduce the amount of noise-emitting traffic.

5. Transit and the Quality of Life

Air pollution, noise, congestion, accidents and the land consumed by roads and parking severely hinders attempts to improve the quality of urban life. The introduction of automobiles initially met with considerable opposition because of its adverse effects on the environment. As auto travel became more and more popular, most of the objections faded away. Today, the automobile has transformed the urban economy, lifestyles and the environment so dramatically that the negative impacts of auto use are again an issue.

It is well-recognized that the world's most "liveable" cities are ones which recognized the impact of the automobile and invested heavily in the alternative -- transit services. Several impacts of the automobile on urban living should be recognized.

First, a significant environmental criterion relating to automobile facilities is intrusion including noise, visual and community effects. Highway or roadway construction often means a loss of privacy for residents living adjacent to these facilities. A number of studies have shown that people are very bothered by the intrusiveness of traffic in their community, sometimes even more than crime.

Second, the automobile can have a major impact on a community in terms of displacement of homes and businesses. With such large land requirements, highways can cut large swathes through neighbourhoods and force local employers to re-located their businesses to other areas. As well, the new facility, when constructed, may markedly alter social, economic, land use and travel patterns in its vicinity in ways which local

residents find detrimental. The impact of a transportation facility in terms of displacement and relocation of persons and families is not adequately reflected by merely comparing the numbers of people affected. A street improvement or new highway can result in severance of education and community facilities from the areas they serve. It can isolate existing shopping facilities or make them obsolete.

Third, the automobile represents a safety hazard to children and pedestrians. In response, neighbourhoods have been designed to minimize through traffic to preserve the amenities of the neighbourhood and to reduce conflicts between pedestrians and automobiles. Despite these designs, a recent study found traffic hazards to be the most common neighbourhood transportation problem.

Fourth, the automobile can cause property damage, particularly from air pollution. Such damages are often overlooked because it is so difficult to quantify. Nonetheless, it can be very noticeable.

Fifth, the movement and storage of vehicles and the resulting architectural and visual impacts often defeats any attempt at what architects and planners call "human scale". Streets become devoted to machinery rather than people. Architectural settings are ruined by parked vehicles and that indifference to visual intrusion leads eventually to a slovenly disregard for the quality of the surroundings.

Finally, the role of transit, particularly the SkyTrain, in the continued growth and vitality of Vancouver's downtown core should be recognized. Unlike major American cities whose downtown areas are deserted at night and on weekends as workers migrate to suburban areas, Vancouver's downtown core remains a safe, active, vibrant centre in off-peak periods with significant local population. Part of the credit for the continued health of Vancouver's downtown core must go to transit which has permitted the development of large shopping, office and retail and recreational developments which attract off-peak users.

In summary, when it comes to transporting large volumes of people in urban areas, transit is less environmentally disruptive than the automobile. In many cases, rapid transit lines can be isolated from the environment. Although the initial construction of a rapid transit line may be disruptive, once it is in operation, it has almost no day-to-day impact. Its minimal noise and vibration only occasionally cause concern especially when the alternatives are considered.

In terms of surface transit, buses and trolley coaches do cause some intrusion. However, one can easily argue that a bus is in fact less intrusive on a per passenger basis. Given a choice, most urban residents would prefer a few buses running down an arterial road to a continuous traffic flow with 1.3 persons per car.

6. Transit's Role in the Environment

The preceding chapters have outlined the importance of transit to the life of a community in terms of contributing to the environmental well-being of the area. Transit in the Greater Vancouver Regional District contributes to the environment by reducing air pollution, noise, congestion, accidents and the land consumed by roads and parking facilities. When it comes to transporting large volumes of people in urban areas, transit is environmentally less disruptive than the automobile. Transit also contributes to the growth and vitability of the urban core and other present and planned major activity centres.

On a passenger-kilometer basis, the conventional diesel bus is eight times more energy efficient than the automobile. As a result, the diesel bus produces one-quarter the amount of nitrogen oxides, one-twentieth the amount of carbon monoxide and one-fiftieth the amount of hydrocarbons that automobiles tend to produce. Carbon dioxide, a large part of automobile exhaust emissions, is also of concern, contributing as it does to the greenhouse effect. Since trolley buses and SkyTrain vehicles produce negligible air pollution due to the prevalence of hydro-electricity in British Columbia, these will be important components of any environmental strategy for transit in the future.

This concluding chapter focuses on what Vancouver might be like today if transit had not had such a high local and provincial priority. This theoretical view of Vancouver without transit illustrates the types of social costs which might result in the absence of transit. The basis of the illustration is the peak period travel to downtown Vancouver. Two case studies are illustrated: one in which no transit is available and one in which there is a five percent increase in the modal split for transit.

If the 385,000 revenue passengers who currently use BC Transit on an average business day had to travel by automobile, approximately 296,000 extra auto trips would be made throughout the Greater Vancouver Regional District. Based on an average trip length of 12 kilometers, an extra 966 million kilometers would be driven each year.

Approximately 32,800 people currently use transit to travel downtown during the morning rush period. If these people drove, more than 25,200 extra cars would be competing for roadway and parking space in downtown Vancouver. If these cars were parked in an aboveground parking garage, each space would cost approximately $8,500 to construct. The total construction costs for parking to accommodate all the extra cars arriving downtown would exceed $200 million. An even greater expense would be incurred if the cars were parked in underground or partially underground facilities. The space required for the parking facilities would amount to approximately 757 thousand square metres.

In addition, extensive highways would be needed to provide access to the downtown. If the 25,200 extra cars travelling to the downtown during the morning peak period were evenly spread throughout the two hours, 8 extra highway lanes would be required. If, on the other hand, 65 percent of the peak period trips occurred during the peak hour, 10 extra highway lanes would be needed. The cost of building 8 lanes of highway for a total of 12 kilometres would amount to almost $50 million if construction occurred on undeveloped land.

The extra mileage on regional roads would burn almost 116 million litres of gas each year. If regular unleaded fuel from full service gas stations is used, $64 million would be spent to fuel the extra automobiles. The additional auto costs to consumers (excluding gas) would total $184 million per year. With more cars on the road, pollution levels would rise. It is estimated that 22.2 million kilograms of additional carbon monoxide emissions, 3.0 million kilograms of additional hydrocarbon emissions and 1.6 million kilograms of additional nitrous oxide emissions would result.

Without rapid transit, land use in Greater Vancouver would be geared towards the automobile. As mentioned, significant land would be required to accommodate the necessary road and parking infrastructure. The density of development in a given area of the city would be lower than when rapid transit is available, due to the need to accommodate parked cars, and as such, it is doubtful that developments such as MetroTown would exist. An automobile-based transportation system, even when augmented by buses, is not capable of comfortably supporting residential and employment densities that occur in most major urban centres. Strip highway development, currently associated with suburban areas, would become increasingly common. The greater distances between establishments would be to the detriment of pedestrians and cyclists, and would not contribute to the development of compact business districts.

Vancouver's residential areas would be considerably different if transit was not available. Many of the residential neighbourhoods which currently exist in Vancouver would have been sacrificed to make way for the highway infrastructure necessary to accommodate the automobiles arriving downtown during the morning rush period. Overall, there would be a drastic reduction in the density of downtown residential development and consequently longer journey-to-work trips as many residents would travel to centrally located workplaces from their suburban homes.

One has to wonder whether Vancouver could be a "liveable region" without transit. The environmental and land use impacts of an extensive urban freeway and road network for instance would severely affect the quality of life in the region. It is doubtful that current standards for parks and open space could be maintained in a highly auto-oriented city and it's impossible that the quality of air in the region would be anywhere near as good as it is now. The majority of workers in an urban area without transit would be severely inconvenienced by automobile congestion during daily worktrips. Automobile congestion would lengthen the weekday rush periods by several hours, which in turn would result in a reduction in the amount of leisure time available to individuals.

This brief theoretical view of the GVRD without transit is useful in illustrating the types of social costs which might result in the absence of transit. Not only would personal expenditures on transportation be higher, but significant public and private sector resources would be devoted exclusively to accommodating the automobile. As well, society would be burdened with higher pollution levels and a reduced quality of life.

In summary, urban transit in the Greater Vancouver Regional District now saves the residents and environment of the lower mainland every year:

116 MILLION LITRES OF GASOLINE

26 MILLION KILOGRAMS OF POLLUTANTS

8 MILLION KILOGRAMS OF ROAD DUST

$278 MILLION IN AUTOMOBILE AND HIGHWAY COSTS

If additional funds could be invested in public transit with the objective of encouraging another five percent of the peak period trips to use transit instead of private automobiles, the transit system could save the residents and the environment of the lower mainland every year:

22.6 MILLION LITRES OF GASOLINE

5.3 MILLION KILOGRAMS OF POLLUTANTS

1.5 MILLION KILOGRAMS OF ROAD DUST

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Appendix:
TABLES

Table 1:
FLOW OF ENERGY IN BRITISH COLUMBIA IN 1987 (Petajoules)

	Hydro-Power	Natural Gas	Refined Petroleum	Coal & Other	Total Energy
Residential	40	61	16	--	118
Commercial	35	33	12	--	80
Transportation	--	1	212	--	213
Industrial	92	78	53	190	412
Sector's Own Use	--	--	21	4	25
Non-Energy Use	--	--	25	--	25
Transmission Loss	16	8	--	--	25
Secondary Demand	185	180	339	194	898
Converted to Electricity	-7	4	3	6	6
Primary Demand	178	184	342	200	904

Source: British Columbia Energy Supply and Requirements Forecast Update 1987-1992. Forecasts and Special Projects Branch, Energy Resources Division, Ministry of Energy Mines and Petroleum Resources, December 1987, pages 40-41.

Table 2:
ENERGY SUPPLY IN BRITISH COLUMBIA (Petajoules)

	1986	1987	1988	1989	1990	1991	1992
Hydroelectricity	171	178	180	185	187	190	196
Natural Gas	184	184	201	209	217	220	226
Petroleum	331	342	338	337	339	340	339
Coal and Other	197	200	207	213	220	222	224
Total Supply	883	904	926	944	963	972	984

Source: British Columbia Energy Supply and Requirements Forecast Update 1987-1992. Forecasts and Special Projects Branch, Energy Resources Division, Ministry of Energy Mines and Petroleum Resources, December 1987, pages 40-41.

Table 3:
ENERGY DEMAND IN BRITISH COLUMBIA (Petajoules)

	1986	1987	1988	1989	1990	1991	1992
Residential	122	118	129	131	134	135	136
Commercial	81	80	86	88	91	94	96
Transportation	205	213	205	205	206	207	206
Industrial	399	412	426	437	447	449	456
Sector's Own Use	23	25	25	24	25	25	24
Non-Energy Use	23	25	24	24	24	24	24
Transmission Loss	24	25	25	26	26	27	28
Energy Conversion	6	6	7	7	10	12	14
Total Demand	883	904	926	944	963	972	984

Source: British Columbia Energy Supply and Requirements Forecast Update 1987-1992. Forecasts and Special Projects Branch, Energy Resources Division, Ministry of Energy Mines and Petroleum Resources, December 1987, pages 40-41.

Table 4:
TRENDS IN TRANSPORTATION ENERGY DEMAND (Petajoules)

Mode	Canada			British Columbia		
	1973	1986	1990	1973	1986	1990
Road	1181	1434	1478	139	168	166
Gasoline	1106	1139	1130	130	134	127
Diesel	75	274	321	9	32	36
Other	0	21	27	0	2	3
Air	126	163	185	15	19	21
Rail	101	75	88	12	9	10
Marine	132	75	84	16	9	9
Total Demand	1541	1747	1835	181	205	206

Source: Canadian Energy Supply and Demand 1987-2005. National Energy Board of Canada, Ottawa, Ontario, September 1988, page 57. The total figure for BC is prorated by mode from the Canadian values.

Table 5:
DISTRIBUTION OF TRANSPORTATION ENERGY DEMAND (Petajoules)

Mode	Canada		British Columbia	
	Total	Percent	Total	Percent
Car	770	44.1%	90	44.1%
Truck	651	37.3%	76	37.3%
Transit	13	0.7%	2	0.7%
Air	163	9.3%	19	9.3%
Rail	75	4.3%	9	4.3%
Marine	75	4.3%	9	4.3%
Total Demand	1747	100.0%	205	100.0%

Source: Canadian Energy Supply and Demand 1987-2005. National Energy Board of Canada, Ottawa, Ontario, September 1988, page 59. The total figure for BC is prorated by mode from the Canadian values.

Table 6:
ENERGY EFFICIENCY OF VARIOUS TRANSPORT MODES

Mode	Psgrs Per Vehicle		Energy Per Vehicle-Km (mJ/km)	Energy Per Psgr-Km	
	Average Daily	Rush Hours		Average (mJ/km)	Rush Hour (mJ/km)
Automobile	1.0	1.3	4.16	4.16	3.20
Carpool	2.4	3.6	4.16	1.73	1.16
Vanpool	5.0	7.2	4.80	0.96	0.67
Diesel Bus	20.0	37.0	19.34	0.97	0.52
Trolley Coach	20.0	37.0	7.38	0.37	0.20
Articulated Diesel	23.0	44.0	24.76	1.08	0.56
Articulated Trolley	23.0	44.0	10.66	0.46	0.24
Light Rail Vehicle	25.0	53.0	9.00	0.36	0.17

Note: Derived from information contained in Table 7 relating to energy consumption by mode and Table 19 relating to average passenger loads.

Table 7:
COMPARISON OF DIFFERENT VALUES OF ENERGY CONSUMPTION

Mode/Reference Source	Regular Service				Express Service				Urban Area Average			
	mpg	L/100km	kwh/km	mJ/km	mpg	L/100km	kwh/km	mJ/km	mpg	L/100km	kwh/km	mJ/km
Private automobile - gas												
ALRT Energy Evaluation[a]	--	--	--	--	--	--	--	--	--	13.5	--	4.68
OC Transpo Study[b]	--	--	--	--	--	--	--	--	--	11.6	--	4.02
National Energy Board[c]	--	--	--	--	--	--	--	--	--	--	--	4.20
Ontario MOT Study[d]	--	--	--	--	--	--	--	--	--	--	--	7.75
GVRD Emission Inventory[e]	--	--	--	--	--	--	--	--	--	13.3	--	4.61
Selected Values	17.42	13.5	--	4.68	25.30	9.3	--	3.22	19.60	12.0	--	4.16
Standard bus - diesel oil												
ALRT Energy Evaluation[a]	--	--	--	--	--	--	--	--	--	56.0	--	21.66
OC Transpo Study[b]	--	51.3	--	19.84	--	37.6	--	14.54	--	44.5	--	17.21
Ontario MOT Study[d]	--	--	--	--	--	--	--	--	--	--	--	21.60
California Energy Commission[f]	3.86	60.9	--	23.56	6.28	37.5	--	14.51	4.56	51.6	--	19.96
GVRD Emission Inventory[e]	--	--	--	--	--	--	--	--	--	49.4	--	19.11
Selected Values	3.92	60.0	--	23.21	6.27	37.5	--	14.51	4.20	50.0	--	19.34
Articulated bus - diesel oil												
OC Transpo Study[b]	--	74.3	--	28.74	--	54.3	--	21.00	--	64.3	--	24.87
Selected Values	3.14	75.0	--	29.01	4.36	54.0	--	20.89	3.67	64.0	--	24.76
Standard bus - methanol												
California Energy Commission[f]	1.39	169.2	--	26.10	2.59	90.7	--	13.99	1.73	136.0	--	20.97
University of California[g]	--	--	--	--	--	--	--	--	1.81	129.9	--	20.04
Selected Values	1.43	165.0	--	25.45	2.58	91.0	--	14.3	1.81	130.0	--	20.05
Trolley bus - electricity												
ALRT Energy Evaluation[a]	--	--	--	--	--	--	--	--	--	--	2.000	7.20
OC Transpo Study[b]	--	--	2.359	8.49	--	--	1.728	6.22	--	--	2.046	7.36
Ontario MOT Study[d]	--	--	--	--	--	--	--	--	--	--	--	10.50
Selected Values	--	--	2.360	8.50	--	--	1.730	6.23	--	--	2.050	7.38
Articulated bus - electricity												
OC Transpo Study[b]	--	--	3.416	12.30	--	--	2.496	8.99	--	--	2.956	10.46
Selected Values	--	--	3.420	12.31	--	--	2.500	9.00	--	--	2.960	10.66
Light rail vehicle - electricity												
ALRT Energy Evaluation[a]	--	--	--	--	--	--	--	--	--	--	2.625	9.45
OC Transpo Study[b]	--	--	2.430	8.75	--	--	2.430	8.75	--	--	2.430	8.75
Selected Values	--	--	2.500	9.00	--	--	2.500	9.00	--	--	2.500	9.00

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Table 8:
TOTAL EMISSIONS BY SOURCE SECTOR (Tonnes)

Source Sector	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
LOWER MAINLAND -- 1985 GVRD Data					
Transportation	47,398	335,635	39,263	2,657	4,685
Fuel Combustion	316	1,822	2,615	887	336
Industrial Processes	6,997	4,359	8,282	8,703	18,865
Waste Incineration	877	2,616	72	5	947
Miscellaneous	22,228	58	0	0	1,398
GVRD Total	**77,816**	**344,490**	**50,232**	**12,252**	**26,231**
BRITISH COLUMBIA -- 1980 EPS Data					
Transportation	102,809	999,950	152,838	12,029	13,397
Fuel Combustion	1,703	10,008	24,749	29,985	6,772
Industrial Processes	78,144	151,508	10,285	124,700	280,953
Waste Incineration	18,996	224,562	1,811	290	19,313
Miscellaneous	53,688	498,411	8,690	0	99,108
BC Total	**255,340**	**1,884,439**	**198,373**	**167,004**	**419,543**
CANADA -- 1980 EPS Data					
Transportation	797,216	7,776,080	1,071,825	136,202	98,405
Fuel Combustion	67,135	481,284	582,167	1,383,627	310,878
Industrial Processes	571,860	608,634	48,126	3,126,770	1,215,741
Waste Incineration	31,162	373,786	4,946	3,013	33,501
Miscellaneous	403,291	1,052,675	18,178	0	248,139
Canada Total	**1,870,664**	**10,292,459**	**1,725,242**	**4,649,612**	**1,906,664**

Source: Assessment of Current and Future Air Quality. Greater Vancouver Regional District, September 1989 and Emissions and Trends of Common Air Contaminants in Canada 1970 to 1980. Report EPS 7/AP/17, Environment Canada, September 1986.

Table 9:
LOWER MAINLAND EMISSIONS BY SECTOR - 1985 (Tonnes)

Source Sector	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
Road	41,514	308,371	32,227	2,077	3,883
Aviation	1,051	6,144	428	46	30
Marine	1,312	7,867	2,137	158	142
Railroads	226	447	950	147	361
Off-Road	3,295	12,806	3,521	229	269
Transportation	**47,398**	**335,635**	**39,263**	**2,657**	**4,685**
Residential Heating	186	1,643	1,814	425	285
Other Space Heating	130	179	801	462	51
Fuel Combustion	**316**	**1,822**	**2,615**	**887**	**336**
Wood/Paper Industry	477	1,176	1,091	103	12,348
Mineral/Petrol/Chemical	6,520	3,183	7,191	8,600	6,517
Industrial Processes	**6,997**	**4,359**	**8,282**	**8,703**	**18,865**
Solid Waste Incineration	877	2,616	72	5	947
Waste Incineration	**877**	**2,616**	**72**	**5**	**947**
Gasoline Marketing	6,176	0	0	0	0
Other Area Emissions	16,052	58	0	0	1,398
Miscellaneous	**22,228**	**58**	**0**	**0**	**1,398**

Source: Assessment of Current and Future Air Quality. Greater Vancouver Regional District, September 1989, page 4-4.

Table 10:
LOWER MAINLAND TOTAL MOTOR VEHICLE EMISSIONS - 1985

Vehicle Segment	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
Light Duty Gas Vehicle	26,809	200,475	16,354	618	902
Light Duty Gas Truck	1,612	12,280	1,109	55	59
Medium Duty Gas Truck	7,485	48,849	3,902	136	147
Heavy Duty Gas Truck	3,854	40,510	1,785	55	253
Motorcycle	308	967	51	2	7
Light Duty Diesel Vehicle	22	63	87	36	86
Light Duty Diesel Truck	16	35	51	22	46
Heavy Duty Diesel Vehicle	1,408	5,193	8,887	1,154	2,385
Total	41,514	308,371	32,227	2,077	3,883

Source: 1985 Lower Mainland Emission Inventory - Mobile Sources. Volume 2: Methodology. GVRD Pollution Control, Greater Vancouver Regional District, May 1988 (values were prorated in order to match the total value contained in Assessment of Current and Future Air Quality. Greater Vancouver Regional District, September 1989).

Table 11:
LOWER MAINLAND MOTOR VEHICLE FLEET - 1985

Vehicle Segment	Number of Vehicles	Veh-Km Per Vehicle	Total Veh-Km (000's)	Fuel Consumed Average (L/100km)	Fuel Consumed Total (000's)
Light Duty Gas Vehicle	706,261	12,040	8,505,207	13.3	1,131,193
Light Duty Gas Truck	41,988	13,160	552,594	18.0	99,467
Medium Duty Gas Truck	101,935	13,590	1,385,385	18.0	249,369
Heavy Duty Gas Truck	24,308	16,340	397,282	25.5	101,307
Motorcycle	30,647	2,670	81,721	6.0	4,903
Light Duty Diesel Vehicle	8,388	12,040	101,018	10.0	10,102
Light Duty Diesel Truck	4,073	13,330	54,310	11.3	6,137
Heavy Duty Diesel Vehicle	15,600	42,410	661,560	49.4	326,811
Total	933,200	12,560	11,739,077	16.4	1,929,289

Source: 1985 Lower Mainland Emission Inventory - Mobile Sources. Volume 2: Methodology. GVRD Pollution Control, Greater Vancouver Regional District, May 1988.

Table 12:
LOWER MAINLAND MOTOR VEHICLE EMISSION RATES - 1985 (gm/km)

Vehicle Segment	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
Light Duty Gas Vehicle	3.146	23.571	1.909	0.072	0.100
Light Duty Gas Truck	2.911	22.222	1.992	0.98	0.100
Medium Duty Gas Truck	5.392	35.260	2.797	0.097	0.100
Heavy Duty Gas Truck	9.680	101.967	4.462	0.136	0.600
Motorcycle	3.758	11.831	0.621	0.021	0.080
Light Duty Diesel Vehicle	0.213	0.622	0.852	0.349	0.800
Light Duty Diesel Truck	0.285	0.649	0.934	0.396	0.800
Heavy Duty Diesel Vehicle	2.125	7.850	13.340	1.729	3.400
Average	3.529	26.269	2.726	0.175	0.312

Source: 1985 Lower Mainland Emission Inventory - Mobile Sources. GVRD Pollution Control, Greater Vancouver Regional District, May 1988 (calculated average values used in report).

Table 13:
SELECTED VEHICLE EMISSION RATE VALUES (gm/km)

Mode	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
Automobile	3.15	23.57	1.91	0.07	0.10
Carpool	3.15	23.57	1.91	0.07	0.10
Vanpool	3.62	27.11	2.20	0.08	0.12
Diesel Bus	2.13	30.00	13.34	1.73	3.40
Articulated Diesel	2.73	38.41	17.08	2.22	4.35
Methanol Bus	0.21	0.44	9.88	0.00	0.01
Trolley Coach	.006	.022	.119	.008	.005
Articulated Trolley	.008	.032	.171	.012	.008
Light Rail Vehicle	.007	.027	.146	.010	.007

Source: Derived from information in Table 16: Comparison of Different Emission Rates.

Table 14:
EMISSION RATES PER PASSENGER (gm/psgr-km)

Mode	HC	CO	NO_x	SO_x	PM
Daily Average					
Automobile (1.0 psgrs)	3.15	23.57	1.91	0.07	0.10
Car Pool (2.4 psgrs)	1.31	9.82	0.80	0.03	0.04
Van Pool (5.0 psgrs)	0.72	5.42	0.44	0.02	0.02
Diesel Bus (20 psgrs)	0.11	1.50	0.67	0.09	0.17
Articulated Diesel (23 psgrs)	0.12	1.67	0.74	0.10	0.19
Methanol Bus (20 psgrs)	0.01	0.02	0.49	0.00	0.00
Trolley Coach (20 psgrs)	.000	.001	.006	.000	.000
Articulated Trolley (23 psgrs)	.000	.001	.007	.001	.000
Rail Transit (25 psgrs)	.000	.001	.006	.000	.000
Rush Hours					
Automobile (1.3 psgrs)	2.42	18.13	1.47	0.05	0.08
Car Pool (3.6 psgrs)	0.88	6.55	0.53	0.02	0.03
Van Pool (7.2 psgrs)	0.50	3.77	0.31	0.01	0.02
Diesel Bus (37 psgrs)	0.06	0.81	0.36	0.05	0.09
Articulated Diesel (44 psgrs)	0.06	0.87	0.39	0.05	0.10
Methanol Bus (37 psgrs)	0.01	0.01	0.27	0.00	0.00
Trolley Coach (37 psgrs)	.000	.001	.003	.000	.000
Articulated Trolley (44 psgrs)	.000	.001	.004	.000	.000
Rail Transit (53 psgrs)	.000	.001	.003	.000	.000

Source: From Table 13: Selected Vehicle Emission Rates and Table 18: Vehicle Loads.

Table 15:
COMPARISON OF DIFFERENT BUS/CAR EMISSION RATIOS

Mode	HC	CO	NO_x	SO_x	PM
Bus/Car Ratios (Vehicle Basis)					
Recent EPA Study	2.00	4.00	10.00	--	500.0
APTA Transit 2000 Study	1.36	2.87	10.60	--	--
Calculated From Above	0.68	1.27	6.98	24.71	34.0
Bus/Car Ratios (Passenger Basis)					
EPA Study (2/30 Psgrs)	0.13	0.27	0.67	--	33.3
APTA Transit 2000 Study	0.10	0.20	0.75	--	--
Ontario MOT 1979 Study	0.09	0.06	0.13	0.50	0.1
Calculated From Above	0.02	0.05	0.25	0.87	1.20

Table 16:
COMPARISON OF DIFFERENT VALUES OF EMISSIONS

Mode/Reference Source	HC			CO			NO			SO			PM		
	g/bhph	g/mi	g/km	g/bhph	g/mi	g/km	g/bhph	g/mi	g/km	g/bhph	g/mi	g/km	g/bhph	g/mi	g/km
Private automobile - gas															
GVRD Emission Inventory[a]	--	--	3.15	--	--	23.57	--	--	1.91	--	--	0.07	--	--	0.10
APTA Transit 2000 Study[b]	--	2.51	1.56	--	18.07	11.23	--	2.47	1.54	--	--	--	--	--	--
TTC (Environment Canada)[c]	--	--	3.04	--	--	22.03	--	--	2.20	--	--	--	--	--	--
Motor Vehicle Safety Act															
Standards Before 1987	--	--	1.24	--	--	15.50	--	--	1.92	--	--	--	--	--	--
September 1987 Standard	--	--	0.25	--	--	2.10	--	--	0.62	--	--	--	--	--	0.12
United States EPA															
1977-79 Standards	--	1.50	0.93	--	15.0	9.32	--	2.00	1.24	--	--	--	--	--	--
1980-81 Standards	--	0.41	0.25	--	7.0	4.35	--	2.00	1.24	--	--	--	--	--	--
1981-83 Standards	--	0.41	0.25	--	3.4	2.11	--	1.00	0.62	--	--	--	--	--	--
Selected Values	--	--	**3.15**	--	--	**23.57**	--	--	**1.91**	--	--	**0.07**	--	--	**0.10**
Standard bus - diesel oil															
GVRD Emission Inventory	--	--	2.13	--	--	7.85	--	--	13.34	--	--	1.73	--	--	3.40
APTA Transit 2000 Study	--	3.40	2.11	--	51.85	32.22	--	26.18	16.27	--	--	--	--	--	--
EPA's Transient Bus Cycle[d]															
GM Diesel	--	--	--	--	--	--	--	--	--	--	0.86	0.53	--	6.24	3.88
Los Angeles Basin Methanol Study[e]															
GM Diesel	--	--	--	--	--	--	--	--	--	--	0.81	0.50	--	6.28	3.90
GM Methanol	--	--	--	--	--	--	--	--	--	--	0.00	0.00	--	0.63	0.39
MAN Methanol	--	--	--	--	--	--	--	--	--	--	0.00	0.00	--	0.06	0.04
EPA's Emission Certification Procedure[f]															
GM Diesel	1.16	--	1.66	1.55	--	2.22	2.47	--	3.53	0.06	--	0.09	0.82	--	1.17
Ontario MOT Tests of Bus Engines[g]															
DDA 6V71 Diesel	1.36	--	1.94	1.92	--	2.74	10.80	--	15.44	--	--	--	0.17	--	0.24
MAN Diesel	0.49	--	0.70	1.82	--	2.60	9.61	--	13.73	--	--	--	0.23	--	0.33
MAN Methanol (M100)	0.03	--	0.04	0.15	--	0.21	4.32	--	6.17	--	--	--	0.01	--	0.01
MAN Methanol (M85)	0.15	--	0.21	0.31	--	0.44	6.91	--	9.88	--	--	--	0.01	--	0.01
California Energy Commission[h]															
Typical Diesel	.4-.6	--	0.70	2-3	--	3.60	5-9	--	10.00	*0.05	--	*0.07	.5-.6	--	0.79
GM Methanol	1.28	--	1.83	1.31	--	1.87	2.20	--	3.14	*0.15	--	*0.21	0.17	--	0.24
MAN Methanol	0.07	--	0.10	0.28	--	0.40	5.75	--	8.22	*0.05	--	*0.07	0.02	--	0.03
Motor Vehicle Safety Act															
1988 Standards	0.48	--	1.86	5.77	--	22.15	2.20	--	8.44	--	--	--	0.22	--	0.86
United States EPA															
1988 Standards	1.30	--	1.86	15.50	--	22.15	10.70	--	15.29	--	--	--	0.60	--	0.86
1990 Standards	1.30	--	1.86	15.50	--	22.15	6.00	--	8.56	--	--	--	0.60	--	0.86
1991 Standards	1.30	--	1.86	15.50	--	22.15	5.00	--	7.15	--	--	--	0.10	--	0.14
1994 Standards	1.30	--	1.86	15.50	--	22.15	5.00	--	7.15	--	--	--	0.10	--	0.14
Selected Values	--	--	**2.13**	--	--	**30.00**	--	--	**13.34**	--	--	**1.73**	--	--	**3.40**
Rail transit vehicle - electricity															
APTA Transit 2000 Study	--	0.37	0.23	--	0.74	0.46	--	17.39	10.81	--	--	--	--	--	--
Ontario MOT Energy Study	--	--	0.18	--	--	0.25	--	--	8.75	--	--	13.50	--	--	0.70
Calculation for BC Hydro	--	--	0.01	--	--	0.03	--	--	0.15	--	--	0.01	--	--	0.01
Selected Values	--	--	**0.02**	--	--	**0.08**	--	--	**0.81**	--	--	**2.49**	--	--	**0.48**

(a) 1985 Lower Mainland Emission Inventory - Mobile Sources. GVRD Pollution Control, Greater Vancouver Regional District. May 1988.

(b) APTA Transit 2000 Task Force Final Report. American Public Transit Association, 1989.

(c) Private correspondence from TTC and Inventory Management Division, Conservation & Protection Branch, Environment Canada, January 1990.

(d) Small, K.A. "Reducing Bus Emissions: Comparative Costs and Benefits of Methanol, Particulate Traps, and Fuel Modification". TRB Record 1164.

(e) Frederick, S.J. et al. "Converting Transit to Methanol: Costs and Benefits for California's South Coast Air Basin". TRB Record 1155.

(f) Kanne, D.D. and R.Y. Iwamoto. "A Novel Approach to the Control of Heavy-Duty Diesel Particulate Emissions". SAE Paper 880634.

(g) Goetz, W.A. et al. "Performance and Emissions of Propane, Natural Gas, and Methanol Fuelled Bus Engines". SAE Paper 880494.

(h) Jackson, M.D. and C. Sullivan. "Transit Bus Operation with Methanol Fuel". SAE Paper 850216 (*aldehydes).

Table 17:
1988/89 STATISTICS FOR VANCOUVER REGIONAL TRANSIT SYSTEM

	BCT-BUS	SEABUS	WVMTD	BCRTC	VRTS
Population	--	--	--	--	1,401,258
Peak Vehicles - Total	708	2	22	46	778
- Buses	489	--	22	--	511
- Trolleys	219	--	--	--	219
- SeaBus	--	2	--	--	2
- Rail Units	--	--	--	46	46
Revenue Passengers	88,310,410	1,856,186	2,132,507	13,301,120	105,600,223
Boarded Passengers	142,661,399	3,820,040	2,953,611	23,317,000	172,752,050
Total Hours	2,603,723	10,059	63,926	165,353	2,843,061
Total Kilometers	53,151,541	138,960	1,504,590	6,920,904	61,715,995
Kilometers/Vehicle	75,073	69,480	71,549	152,010	79,326
Kilometers/Hour	20.4	13.8	23.5	41.9	21.7
Average Trip Length (est.)	12.0	3.3	10.0	13.0	11.9
Revenue Passengers	88,310,410	1,856,186	2,132,507	13,301,120	105,600,223
Psgr-Kilometers	1,059,724,920	6,125,414	21,325,070	172,914,560	1,257,529,401
Psgr-Kilometers	1,059,724,920	6,125,414	21,325,070	172,914,560	1,257,529,401
Vehicle-Kilometers	53,151,541	138,960	1,504,590	6,920,904	61,715,995
Daily Avg Vehicle Load	20	44	14	25	20
Peak Avg Vehicle Load*	37	161	37	53	38
Vehicle Capacity - Seated	43	400	43	80	46
- Total	80	400	80	150	85
- Design	55	400	55	80	57
Peak Avg Vehicle Load	37	161	37	53	38
Design Capacity	55	400	55	80	57
Load Over Capacity (%)*	67	40	67	66	67

Source: 1990-1991 Annual Service Plan, BC Transit, July 1989.
Note: *Average Load over Capacity from screenline counts in peak period = 67% (37/55 psgrs) and for seabus = 40% (161/400 psgrs)

Table 18:
AVERAGE PASSENGER LOAD PER VEHICLE

Reference Source	Rail Transit	Artic Bus	Transit Bus	Van Pool	Car Pool	Auto-mobil
Daily Average						
Estimate for BC Transit	25	23	20	--	--	--
CUTA Transit Fact Book	100	--	40	6.0	--	1.3
MTC Ridesharing Study	76	--	40	--	--	--
Selected Average Loads	25	23	20	5.0	2.4	1.0
Rush Hours						
Estimate for BC Transit	53	44	37	--	--	--
APTA Transit 2000 Study	37	--	17	7.2	3.6	1.2
CUTA Transit Fact Book	200	--	67	10.0	4.0	1.3
MTC Ridesharing Study	320		100	12.0	5.0	1.0
Selected Rush Loads	53	44	37	7.2	3.6	1.3

Sources: Energy Conservation Through Transit and Ridesharing, Transportation Energy Management Program, Ontario Minstry of Transportation and Communications, 1983.
Urban Transit Facts in Canada: 1987 Data, Canadian Urban Transit Association, December 1988.
APTA Transit 2000 Task Force Final Report, American Public Transit Association, 1989.

Table 19:
CALCULATION OF EMISSIONS FROM ELECTRIC POWER GENERATION

Mode	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
British Columbia					
Power Gen. Emissions (tons)	142	557	2995	205	135
Electric Power Generated			185 petajoules		
Emission Rate (gm/mJ)	0.00077	0.00301	0.01619	0.00111	0.00073
Canada					
Power Gen. Emissions (tons)	5,833	20,228	228,802	767,727	147,676
Electric Power Generated			1,389 petajoules		
Emission Rate (gm/mJ)	0.00420	0.01456	0.16468	0.55256	0.10629
BC Emission Rate (gm/mJ)	0.00077	0.00301	0.01619	0.00111	0.00073
Emissions by Mode (gm/km)					
Trolley (7.38 mj/km)	0.006	0.022	0.119	0.008	0.005
Artic (10.56 mj/km)	0.008	0.032	0.171	0.012	0.008
Light Rail (9.00 mj/km)	0.007	0.027	0.146	0.010	0.007

Note: Total electrical energy produced in BC was 185 petajoules and in Canada was 1,389 petajoules. Emissions from power generation from Emissions and Trends of Common Air Contaminants in Canada: 1970 to 1980. Report EPS 7/AP/17, Environment Canada, 1986.

Table 20:
AVERAGE EMISSIONS PER TRANSIT PASSENGER

Mode	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
Emissions by Mode (gm/psgr-km)					
Diesel Bus	0.0580	0.8110	0.3610	0.0470	0.0920
Trolley Coach	0.0002	0.0006	0.0032	0.0002	0.0001
Light Rail	0.0001	0.0005	0.0027	0.0002	0.0001
Average per Passenger	0.035	0.489	0.219	0.028	0.056

Note: Existing proportion of passengers by mode was used to calculate average (60% on diesel buses, 26% on trolley coaches, and 14% on light rail vehicles).

Table 21:
POTENTIAL SAVINGS IN AIR POLLUTION
(Using Transit for a Year Instead of Driving to Work)

Mode	Hydro Carbons HC	Carbon Monoxide CO	Nitrogen Oxides NO_x	Sulphur Oxides SO_x	Particulate Matter PM
Driving to Work:					
Emissions per Kilometer (gm)	2.423	18.131	1.469	0.054	0.077
Kilometers Driven			5,640 (12 km x 235 days x 2)		
Total Emissions (kg)	13.666	102.258	8.286	0.304	0.434
Using Public Transit:					
Emissions per Kilometer (gm)	0.035	0.489	0.219	0.028	0.056
Passenger Kilometers			5,640 (12 km x 235 days x 2)		
Total Emissions (kg)	0.196	2.761	1.234	0.160	0.313
Savings per Kilometer (gm)	2.39	17.64	1.25	0.03	0.02
Total Annual Savings (kg)	13.47	99.50	7.05	0.14	0.12

Table 22:
NUMBER OF TRIPS IN THE GVRD BY TIME OF DAY

	6-9 am Peak		3-6 pm Peak		Total Peak		Total 24-Hour	
	GVRD	CBD	GVRD	CBD	GVRD	CBD	GVRD	CBD
1985 GVRD O-D SURVEY RESULTS								
Auto Driver	364,313	38,220	513,766	19,051	878,079	57,271	1,945,046	113,850
Auto Psgr	115,896	8,278	181,102	4,134	296,998	12,412	717,639	31,024
Transit Psgr	71,771	24,956	90,844	7,595	162,615	32,551	260,616	53,080
Total	**551,980**	**71,454**	**785,712**	**30,780**	**1,337,692**	**102,234**	**2,923,301**	**197,954**
1990 CONSULTANTS ESTIMATES								
Auto Driver	466,321	48,922	657,620	24,385	1,123,941	73,307	2,489,659	145,728
Auto Psgr	148,347	10,596	231,811	5,292	380,157	15,887	918,578	39,711
Transit Psgr	105,503	36,685	133,541	11,165	239,044	47,850	383,106	78,028
Total	**720,171**	**96,203**	**1,022,972**	**40,841**	**1,743,143**	**137,044**	**3,791,342**	**263,466**
Mode Split	14.6%	38.1%	13.1%	27.3%	13.7%	34.9%	10.1%	29.6%

Source: 1985 Metropolitan Vancouver Origin-Destination Survey: Inter-Municipal Travel Patterns. GVRD Development Services, Greater Vancouver Regional District, Burnaby, B.C.

Table 23:
NUMBER OF AM PEAK PERIOD DOWNTOWN-ORIENTED TRIPS

	Private Transportation				Public Transportation			
	Auto	Truck	Taxi	Total	Bus	SkyTrain	SeaBus	Total
1985 GVRD SCREENLINE SURVEY								
Vehicles	38,107	1,580	618	40,305	709	0	12	721
Passengers	47,976	1,989	778	50,743	28,351	0	1,500	29,851
Occupancy				1.26	40	0	0	41
1990 CONSULTANTS ESTIMATES								
Vehicles	46,233	1,917	750	48,900	530	264	12	806
Passengers	58,052	2,407	941	61,400	21,200	14,000	1,500	36,700
Occupancy				1.26	40	53	125	46
Veh Percent	93.0%	3.9%	1.5%	98.4%	1.1%	0.5%	0.0%	1.6%
Psgr Percent	59.2%	2.5%	1.0%	62.6%	21.6%	14.3%	1.5%	37.4%

Source: 1985 Metropolitan Vancouver Origin-Destination Survey: Vehicle and Passenger Screenline Survey. GVRD Development Services, Greater Vancouver Regional District, Burnaby, B.C.

Table 24:
DISTRIBUTION OF TRANSIT RIDERSHIP BY TIME OF DAY

	AM Peak Period			Daily Peak Periods			Daily	Annual
	1-Hr	2-Hr	3-Hr	AM	PM	Total	Riders	(000's)
1985 GVRD O-D SURVEY/SCREENLINE								
Total Trips	31,300	63,800	71,771	71,771	90,844	162,615	260,616	71,483
CBD Trips	14,270	26,544	29,851	24,956	7,595	32,551	53,080	
1990 CONSULTANTS ESTIMATES								
Total Trips	46,200	94,300	106,000	106,000	134,200	240,200	385,000	105,600
CBD Trips	17,600	32,800	36,700	36,700	11,200	47,900	78,400	

Source: 1985 Metropolitan Vancouver Origin-Destination Survey: Vehicle and Passenger Screenline Survey. GVRD Development Services, Greater Vancouver Regional District, Burnaby, B.C.

Table 25:
SHIFTING TRIPS FROM THE AUTOMOBILE TO TRANSIT

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	←--- ---→ 0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Total Daily Peak Period Transit Trips	352,725	315,150	277,575	240,000	202,425	164,850	127,275	0
Total Daily Peak Period Auto Trips	1,390,275	1,427,850	1,465,425	1,503,000	1,540,575	1,578,150	1,615,725	1,743,000
Daily Peak Period Person-Trips Shifted	112,725	75,150	37,575	0	-37,575	-75,150	-112,725	-240,000
Percent of Peak Travel by Transit	20.2%	18.1%	15.9%	13.8%	11.6%	9.5%	7.3%	0.0%

Table 26:
SAVINGS IN TRAFFIC CONGESTION

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	←--- ---→ 0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Daily Peak Period Auto Person-Trips Saved	112,725	75,150	37,575	0	-37,575	-75,150	-112,725	-240,000
AM Peak Period Auto Person-Trips Saved	44,292	29,528	14,764	0	-14,764	-29,528	-44,292	-94,300
CBD Peak Period Auto Person-Trips Saved	15,406	10,271	5,135	0	-5,135	-10,271	-15,406	-32,800
CBD Peak Period Auto Vehicle-Trips Saved	11,851	7,900	3,950	0	-3,950	-7,900	-11,851	-25,231

Table 27:
EFFECT ON TRANSIT RIDERSHIP

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	←--- ---→ 0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Annual Revenue Passengers (thousands)	136,519	126,213	115,907	105,600	95,294	84,988	74,681	0
Daily Transit Revenue Passengers	497,725	460,150	422,575	385,000	347,425	309,850	272,275	0
Peak Period Transit Revenue Passengers	310,270	286,847	263,423	240,000	216,577	193,153	169,730	0
AM Peak Period Transit Passengers	121,910	112,707	103,503	94,300	85,097	75,893	66,690	0
AM Peak Downtown Transit Passengers	42,404	39,202	36,001	32,800	29,599	26,398	23,196	0

Table 28:
ANNUAL SAVINGS IN FUEL CONSUMPTION

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	←--- ---→ 0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Annual Transit Revenue Passengers (millions)	136.5	126.2	115.9	105.6	95.3	85.0	74.7	0
Transit Passenger-Kilometers (millions)	1,624.6	1,501.9	1,379.3	1,256.6	1,134.0	1,011.4	888.7	0
Equivalent Automobile-Kilometers (millions)	1,249.7	1,155.3	1,061.0	966.6	872.3	778.0	683.6	0
Savings in Annual Automobile-Kms (millions)	283.0	188.7	94.3	0	-94.3	-188.7	-283.0	-966.6
Savings in Annual Fuel Usage (millions)	34.0	22.6	11.3	0	-11.3	-22.6	-34.0	-116.0
Savings in Annual Fuel Costs (millions)	$18.7	$12.5	$6.2	0	-$6.2	-$12.5	-$18.7	-$63.8

Note: Fuel consumption assumed to be 12 litres per 100 kilometers and fuel cost assumed to be $0.55 per litre.

Table 29:
ANNUAL SAVINGS IN AIR POLLUTION

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Annual Transit Revenue Passengers (millions)	136.5	126.2	115.9	105.6	95.3	85.0	74.7	0
Transit Passenger-Kilometers (millions)	1,624.6	1,501.9	1,379.3	1,256.6	1,134.0	1,011.4	888.7	0
Savings in Auto Person-Kilometers (millions)	367.9	245.3	122.6	0	-122.6	-245.3	-367.9	-1,256.6
Savings in HC at 2.388 gm/km (tonnes)	878.6	585.8	292.9	0	-292.9	-585.8	-878.6	-3000.9
Savings in CO at 17.641 gm/km (tonnes)	6,490.7	4,327.2	2,163.6	0	-2,163.6	-4,327.2	-6,490.7	-22,168.4
Savings in NO at 1.250 gm/km (tonnes)	459.9	306.6	153.3	0	-153.3	-306.6	-459.9	-1,570.8
Savings in SO at 0.026 gm/km (tonnes)	9.6	6.4	3.2	0	-3.2	-6.4	-9.6	-32.7
Savings in PM at 0.021 gm/km (tonnes)	7.7	5.2	2.6	0	-2.6	-5.2	-7.7	-26.4
Total Annual Savings in Emissions (tonnes)	7,846.6	5,231.1	2,615.5	0	-2,615.5	-5,231.1	-7,846.6	-26,799.2
Percent of Total Annual Emissions	2.0%	1.4%	0.7%	0%	-0.7%	-1.4%	-2.0%	-6.9%

Table 30:
SAVINGS IN HIGHWAY AND PARKING CONSTRUCTION

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Downtown Destined Peak Period Car Trips Saved	11,851	7,900	3,950	0	-3,950	-7,900	-11,851	-25,231
Savings in Parking Construction Costs (millions)	$100.7	$67.2	$33.6	0	-$33.6	-$67.2	-$100.7	-$214.5
Savings in Highway Lane Capacity Requirements	4	3	2	0	-2	-3	-4	-8
Savings in Highway Construction Costs (millions)	$23.8	$17.9	$11.9	0	-$11.9	-$17.9	-$23.8	-$47.6
Savings in Vehicle Operating Costs (millions)	$53.7	$35.8	$17.9	0	-$17.9	-$35.8	-$53.7	-$183.5

Note: Parking construction costs assumed to be $8,500/space; highway capacity assumed to be 1750 vehicles/lane/hour over a two-hour period; highway construction costs assumed to be $500,000/lane-kilometer; and vehicle operating costs assumed to be $0.146/kilometer.

Table 31:
ANNUAL SAVINGS IN HIGHWAY AND RELATED COSTS

If This Percent of Peak Period (7-9am) Automobile Trips Shifted To Transit	Less Car Traffic 7.5%	5.0%	2.5%	0%	More Car Traffic -2.5%	-5.0%	-7.5%	Without Transit
Annual Fuel Consumption Costs (millions)	$ 18.7	$ 12.5	$ 6.2	0	-$ 6.2	-$ 12.5	-$ 18.7	-$ 83.8
Vehicle Operating Costs (millions)	$ 53.7	$ 35.8	$ 17.9	0	-$ 17.9	-$ 35.8	-$ 53.7	-$183.5
Parking Construction Costs (millions)	$ 10.1	$ 6.7	$ 3.4	0	-$ 3.4	-$ 6.7	-$ 10.1	-$ 21.4
Highway Construction Costs (millions)	$ 2.4	$ 1.8	$ 1.2	0	-$ 1.2	-$ 1.8	-$ 2.4	-$ 4.8
Land Acquisition Costs (millions)	$ 2.4	$ 1.8	$ 1.2	0	-$ 1.2	-$ 1.8	-$ 2.4	-$ 4.8
TOTAL ANNUAL HIGHWAY SAVINGS (millions)	$ 87.2	$ 58.6	$ 29.9	0	-$ 29.9	-$ 58.6	-$ 87.2	-$278.2
Annual Transit Total Costs (millions)	$364.3	$336.8	$309.3	$281.8	$254.3	$226.8	$199.3	0
Annual Transit Revenues (millions)	$125.7	$116.2	$106.7	$97.2	$ 87.7	$ 78.2	$ 68.7	0
Net Annual Transit Costs (millions)	$238.6	$220.6	$202.6	$184.6	$166.6	$148.6	$130.6	0
TOTAL ANNUAL TRANSIT INCREASE (millions)	$ 82.5	$ 55.0	$ 27.5	0	-$ 27.5	-$ 55.0	-$ 82.5	-$281.8

Table 32:
ANNUAL SAVINGS TO THE ENVIRONMENT — BY ONE TRANSIT RIDER

Environmental Concern	Quantity Saved	Equivalent Factor
Air Pollution:		
Hydrocarbons	13.47 kilograms	Equal in weight to the amount of pure air (14 kg) that each of us needs each day to survive
Carbon Monoxide	99.50 kilograms	2.6 times the amount required to raise the level of carbon monoxide in BC Place Stadium to dangerous conditions
Carbon Dioxide*	1,917.02 kilograms	0.2 times the amount of carbon removed by one hectare of forest (each hectare removes 2.5 tonnes of carbon)
Nitrogen Oxides	7.05 kilograms	3.3 times the amount required to raise the level of nitrogen oxides in BC Place Stadium to dangerous proportions
Sulphur Oxides	0.14 kilograms	20 times the amount necessary to produce a volume of acid rain equal to the water in an Olympic-size pool
Particulate Matter	0.12 kilograms	About equal to a coffee cup filled with potentially poisonous or disease-producing particles (arsenic, lead, aldehydes)

Table 33:
ANNUAL SAVINGS TO THE ENVIRONMENT — BY ALL TRANSIT RIDERS

Environmental Concern	Quantity Saved	Equivalent Factor
Energy Consumption:		
Gasoline	116.0 million litres	2.8 times the amount spilled in Prince William Sound by the tanker, Exxon Valdez, on March 12, 1989
Air Pollution:		
Hydrocarbons	3,000 tonnes	1.5 times the amount of waste that could be contained in an Olympic-size swimming pool
Carbon Monoxide	22,170 tonnes	9.5 times the amount of carbon removed by the trees every year in Stanley Park (CO oxidized becomes CO)
Carbon Dioxide*	259,648 tonnes	70 times the amount of carbon removed by the trees every year in Stanley Park (2.5 tonnes of carbon per hectare).
Nitrogen Oxides	1,570 tonnes	157 truckloads of material contributing to the depletion of the ozone layer and the increase in ultra-violet radiation
Particulate Matter	30 tonnes	About equal to 3 truckloads filled with potentially poisonous or disease-producing particles (arsenic, lead, aldehydes)
Water Pollution:		
Highway Road Dust	7,800 tonnes	1/4 the amount of waste dumped into the Fraser River each year by the pulp and paper industry.
Noise Pollution:		
Noise Level	unknown	The sounds of an additional 25,000 cars driving to downtown Vancouver each morning between 7:00 am and 9:00 am.
Traffic Congestion:		
Fuel Consumption	$ 64 million	
Operating Costs	$184 million	
Parking Construction	$ 21 million	Enough money to fund the total transit deficit, including capital costs for a year
Highway Construction	$ 5 million	
Land Acquisition	$ 5 million	
	$278 million	

Table 34:
ANNUAL SAVINGS TO THE ENVIRONMENT — BY 5% MODAL SHIFT

Environmental Concern	Quantity Saved	Equivalent Factor
Energy Consumption:		
Gasoline	22.6 million litres	Enough to meet the annual energy requirements of 4,765 average households for a year.
Air Pollution:		
Hydrocarbons	586 tonnes	If confined to a 10km-by-10km area and to a height of 1km, would result in air similar to smoking 36 cigarettes.
Carbon Monoxide	4,327 tonnes	Would require about $428 thousand worth of reforestation to produce enough trees to remove the amount of carbon.
Carbon Dioxide*	50,687 tonnes	13 times the amount of carbon removed by the trees every year in Stanley Park (2.5 tonnes of carbon per hectare).
Nitrogen Oxides	307 tonnes	30 truckloads of material contributing to the depletion of the ozone layer and the increase in ultra-violet radiation
Sulphur Oxides	6 tonnes	About half a truckload of material that produces acid rain, damages vegetation, and destroys building materials
Particulate Matter	5 tonnes	About half a truckload of potentially poisonous or disease-producing particles (arsenic, lead, aldehydes, etc.)
Water Pollution:		
Highway Road Dust	1,524 tonnes	About 3/4 of an olympic-size swimming pool filled with potentially toxic wastes being dumped into our rivers

*estimates for carbon dioxide savings (268.62 gm/km) are based on the Canadian Urban Transit Association Report, "The Environmental Benefits of Urban Transit", Toronto, Ontario, January 1990.

Table 35:
CONVERSION FACTORS

To Convert	Multiply by	To Obtain
British thermal unit (BTU)	X 0.0010604	= Megajoules
Horse-power-hour (Hp-hr)	X 2.6845	= Megajoules
Gallon (U.S.)	X 3.785	= Litres (L)
	X 0.83268	= Gallons (Can.)
Gram/BHp-Hr (brake)	X 2.3 (EPA)	= Gram/mile (g/mi)
	X 0.3725	= Gram/megajoule (g/mJ)
	X 1.4292	= Gram/kilometer (g/km)
Gram/megajoule (g/mJ)	X 3.8367	= Gram/kilometer (g/km)
Joule (J)	X 1	= Newton-meter
	X 0.2389	= Calorie (cal)
	X 2.778×10^{-7}	= Kilowatt-hour (kw-hr)
	X 3.725×10^{-7}	= Horse-power-hour (hp-hr)
	X 9.480×10^{-4}	= British thermal unit (BTU)
Kilometer (km)	X 0.62137	= Mile (mi)
Kilowatt-hours (kWh)	X 3.6	= Megajoules (mJ)
Litres (L)	X 0.26417	= Gallon (U.S.)
Mile (mi)	X 1.6093	= Kilometer (km)
Miles per gallon (mpg)	X 0.42518	= Kilometers per litre (km/L)
Miles per gallon (methanol)	X 0.43077	= Miles per gallon (diesel)
Tonne (metric)	X 1×10^{6}	= Grams (gm)
	X 1000	= Kilograms (kg)
	X 2204.6	= Pounds (lb)

Table 36:
ENERGY CONVERSION FACTORS

This Fuel		Contains this Energy				and Weighs
Natural Gas	=	38.35 mJ/L	or	50.1 mJ/kg	=	
Motor Gasoline	=	34.66 mJ/L	or		=	
Diesel Fuel Oil	=	38.68 mJ/L	or	42.5 mJ/kg	=	0.839 g/mL
Propane	=	25.53 mJ/L	or	46.1 mJ/kg	=	
Ethane	=	18.36 mJ/L	or		=	
Methanol	=	15.43 mJ/L	or	20.0 mJ/kg	=	0.791 g/mL
Electricity	=	3.60 mj/kWh				

Table 37:
METRIC NOMENCLATURE

exa = 10^{18}	peta = 10^{15}	tera = 10^{12}	giga = 10^{9}
mega = 10^{6}	kilo = 10^{3}	hecto = 10^{2}	deca = 10^{1}
deci = 10^{-1}	centi = 10^{-2}	milli = 10^{-3}	micro = 10^{-6}

Table 38:
SOME INTERESTING FACTS

Some Interesting Environmental Facts
The Capilano Water Reservoir contains 16.5 billion gallons of water (75 billion litres or 75 million cubic metres).
According to the U.S. Department of Energy, an average household consumes energy equal to 1,253 gallons of oil per year.
Each year the amount of energy that leaks through windows in the United States equals the amount of oil that flows through Alaskan pipelines.
In British Columbia, six pulp mills dump 32,000 tonnes of waste each year in the Fraser River.
The pulp and paper industry in Canada dump 2,777 tons per day of waste.
All industrial wastes in Canada total 1.7 billion gallons (7.73 million tonnes) which equals the flow over Niagara Falls in 10 hours.
One Olympic size pool contains 440,000 gallons (2,000 tonnes).
The Expo Fair Site covered 70 hectares, Van Dusen Botanical Gardens covers 22.5 hectares (55.5 acres), the PNE Landsite covers 70 hectares (172 acres).
The Exxon Valdez, carrying 200 million litres of Alaska crude to California, was hard aground leaking nearly 42 million litres into Prince William Sound 40 kilometres from Valdez on March 14, 1989.
B.C. Place Stadium is 232 metres long, 190 metres wide and 60 metres high. The circumference is 760 metres. The roof covers 40,000 square metres and the volume is 2,000,000 cubic metres.
One hectare of forest removes 2.5 tonnes of carbon (mainly carbon dioxide) per year from the atmosphere through photosynthesis. The cost of reforestation is estimated at $500 per hectare.
Stanley Park, the largest urban park in Canada, is 405 hectares (1000 acres). The trees in Stanley Park remove about 1,000 tonnes of carbon from the atmosphere each year. Lost Lagoon covers 16.63 hectares and contains about 166,000 tonnes (cubic meters) of water.
One tonne of carbon dioxide contains about 0.27 tonnes of carbon (divide by 44/12). An automobile produces about 268.62 grams of carbon dioxide per kilometer (1987 fleet average emission factor from Environment Canada). Saving 188.7 million auto-kilometres annually (5% shift in peak period modal split) would save 50,688 tonnes of carbon dioxide or 13,824 tonnes of carbon.
One tonne of carbon monoxide contains about 0.43 tonnes of carbon (divide by 28/12 - the molecular weights of carbon monoxide and carbon). Carbon monoxide is oxidized to produce carbon dioxide, a greenhouse gas.
About 30 million hectares are currently devoted to forestry in B.C. According to Dave Spittlehouse, forest climatologist at the B.C. Ministry of Forests, B.C.'s forests accumulate 30 million tonnes of carbon a year, but that is only 25 percent of the carbon released annually in Canada by burning fossil fuels and other emissions.